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ARMY AIRCRAFT VOICE-WARNING SYSTEM STUDY

James E. Brown
Carmine M. Bertone
Richard W. Obermayer

The Bunker-Ramo Corporation

February 1968

AMCMS Code 5122.12.43500

HUMAN ENGINEERING LABORATORIES

**ABERDEEN PROVING GROUND,
MARYLAND**

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FOREWORD

This study of Army aircraft voice-warning systems was performed by The Bunker-Ramo Corporation, Canoga Park, California, for the U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, under Contract No. DAAD05-68-C-0025(X), beginning 10 August 1967 and ending 10 January 1968. Mr. Robert Cassatt was the Technical Monitor. Investigators for this study were James Brown and C. M. Bertone. Mr. Richard Obermayer served as Program Manager for The Bunker-Ramo Corporation.

The accomplishment of this study is directly attributable to the assistance of many individuals and organizations.

The use of the facilities and the assistance of personnel of the Army Aviation School, Fort Rucker, Alabama, Fort Hunter-Stewart, Georgia, and the United States Army Board for Aviation A cident Research, Fort Rucker, Alabama, were instrumental in the success of the program.

Special credit is due to Major J. Neely, Department of Instruction, Fort Rucker, Alabama, for his invaluable assistance to the study team throughout the program. By providing key personnel contacts and making necessary arrangements during the study, he ensured the collection of the required information.

Major H. Grey, Department of Instruction, Fort Hunter-Stewart, Georgia, and Major R. Trent, Department of Instruction, Fort Rucker, Alabama, were instrumental in helping to secure pilots for the questionnaire data which was collected during the study.

Special credit also is due to the many individuals in the Aviation School who assisted in providing pilots for the study. Among these were Colonel H. E. Kelly, Major D. Vosel, Major D. Moeller, Major Nakajo, and Major R. Quisenberry.

Within USABAAR, the study team is particularly grateful for the assistance and guidance provided by Emil Spezia and Major C. Mateer. C. Johnson and his fine staff aided in the collection of the accident statistics for the study.

Finally, Lt. Colonel J. Walker and H. Catey are to be commended for aiding in the collection of data at Edwards Air Force Base, California.

ABSTRACT

This report describes an analytical study that was intended to serve as a basis for the application of voice-warning systems (VWS) for the UH-1B and UH-1D (Huey), AH-1G (Cobra), CH-47 (Chinook), CH-54 (Skycrane), and OV-1 (Mohawk). The following problems of installing a VWS in these Army aircraft were studied: (1) the identification and selection of messages for maximum effectiveness; (2) the determination of priority sequences; and (3) the integration of the VWS into existing cockpits. The study involved the collection of basic data and the conduct and validation of mission analyses, operational sequence diagrams, task analyses, aircraft configuration analyses, pilot opinion surveys, and Army aircraft accident analyses. In this report, priority sequences are derived for all major emergencies for the six vehicles; further analytical effort is described which reduced the list to 20 messages for inclusion in the VWS. For each aircraft, 2 lists of 20 messages are proposed; one list assumes additional sensors, while the second assumes the current sensor system. Recommendations are made for message structure and content, priority sequences, integration of the VWS with the current visual-warning system, general sensor requirements, interlocking between VWS messages, and other related considerations.

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I. INTRODUCTION AND SUMMARY

This study is intended to serve as a basis for the application of voice-warning systems (VWS) to Army aircraft. Voice-warning systems permit playing a taped message into the pilot's headset whenever specific faults are sensed; when more than one fault occurs at one time, a warning is given at a time according to a predetermined priority sequence. The problems of installing a VWS in Army aircraft are: (1) the warnings must be identified and the messages must be carefully selected for maximum effectiveness; (2) the priority sequence must be determined; and (3) the problems of integrating the VWS into existing cockpits must be appraised for necessary action and possible efficiencies that may be realized.

This four-month study was undertaken to investigate these three problem areas for six Army aircraft: UH-1B and UH-1D (Huey), AH-1G (Huey Cobra), CH-47 (Chinook), CH-54 (Skycrane), and OV-1 (Mohawk). To satisfy the program objectives, analyses were conducted in the following areas: (1) information requirements, (2) accident statistics, (3) pilot information surveys, (4) cockpit integration, and (5) message content. An attempt was made to reconcile the various viewpoints of engineers, pilots, and human engineers to achieve a maximum contribution of the VWS to Army aviation safety. These analyses are presented in the following chapters; the specific recommendations of this study are presented in Chapter X.

II. METHOD

A. VOICE-WARNING SYSTEM OPERATION

The voice-warning system (VWS) is capable of playing a number of tape-recorded messages, one at a time, into the pilot's headset when a specific emergency is sensed (Ref. 1). For example, if fire sensors are placed in the fuselage of the aircraft, a voice message stating, "fuselage fire," can alert the pilot to the specific nature of the emergency even though he may be absorbed in some task or looking outside the vehicle.

Each message plays for about 15 seconds; the nature of the message depends entirely upon the needs of the user. Sounds of various kinds (speech, etc.) may be sequenced in any fashion within the duration of the taped message. The NORVIPS system, which is of direct concern in this study, permits a total of 20 messages; systems can be provided which will yield a larger number of messages. The warnings which are normally given to the pilot via the visual annunciator panel (caution panel), can be readily announced to the pilot via the VWS; however, additional warnings can be provided when additional sensors are installed, or, when a signal adapter unit is used, parameters usually restricted to instrument panel displays may be used to create new warnings. A given VWS message may be played when a specific condition exists (e.g., a parameter is out of tolerance) or when a combination of conditions exists (e.g., both of two systems have failed or one or the other of two systems has failed). The VWS therefore allows the user a great deal of flexibility to tailor the system to his specific requirements.

Each message is ranked in a priority sequence. When two failures occur together, the failure that is ranked higher in the priority sequence is played first. The logic employed in the system is as follows. Ordinarily, a message will continue to play through the taped recording, and then continue to repeat until either the pilot over-rides the system or until the fault is corrected. If another fault of lower priority occurs, the corresponding message will be played as soon as the first fault is corrected or the VWS over-ride control is actuated. If another fault of higher priority occurs while another message is playing, the first message will be immediately interrupted, and the second message will begin to play from the beginning.

B. STUDY OBJECTIVES

Three basic issues are raised when one considers the application of the VWS to a given flight vehicle: (1) what messages, and what information, should be presented to the pilot for each possible emergency for

which the VWS may be useful? (2) what should the order of the messages be in the VWS priority sequence? (3) what considerations should be made when installing the VWS in a specific vehicle (e.g., other warning devices exist, other devices display relevant information, and particular vehicle characteristics, such as the noise level, may have to be considered in using the VWS)? The objective of this study was the resolution of these three issues for each of six vehicles (UH-1B, UH-1D, AH-1G, CH-47, CH-54, and OV-1).

1. Messages

Because the VWS permits warning of emergencies for which no explicit warning previously existed (the pilot must deduce the problem from a variety of instruments), a significant requirement is to determine the full set of messages that must be auditorily displayed on the VWS. When each message is identified, one must determine the information to be conveyed, which, in turn, depends on the information requirements of the pilot for each emergency. The nature of, and response to, an emergency may depend on mission and flight conditions. Furthermore, the details of message content and message structure are important, because these details may affect the audibility of the message, the ability to easily discriminate between messages, and the speed and correctness of response. The ability to hear the VWS messages over vehicle noise and other communications, the ability to easily distinguish between VWS messages, and the ability to easily determine the correct initial response to an emergency are three important criteria that were applied in this study.

2. Priority sequence

The determination of the VWS priority sequence is important because it determines which of two messages will be heard first when two faults occur together. If only one fault occurs at a time, the proper message will be played regardless of its position in the priority sequence. The design of the priority sequence then depends on detailed study of multiple failures, asking (for each combination of failures) "which failure should the pilot be informed of first?" Of course, it is possible that the pilot should have knowledge of both failures at the same time to take the correct response for a unique combination of failures. The VWS effectively allows informing the pilot of both failures at the same time, because a third message can be played which depends on both failures being sensed together (using internal and/or logic). In a similar way, if a given emergency depends upon mission or flight conditions, the priority sequence may be made a function of these conditions by using the VWS logic.

3. Cockpit Integration

Currently, the pilot uses many of the displays provided on the instrument panel to diagnose system malfunctions. He spends considerable time scanning these instruments looking for possible problems. The VWS should alleviate much of the need for such instrument scanning because the pilot will be alerted to emergencies as they occur regardless of where he is looking. Performance on many missions should be improved, because, ordinarily, the pilot is required to spend substantial time "heads-up," looking outside the vehicle. It is, therefore, appropriate in this study to investigate if some of the visual and/or auditory displays provided the pilot are not any longer needed. Removal of these visual displays, of course, depends on whether these instruments provide any information in addition to the VWS and whether information redundant to the VWS is required. Moreover, this study considers the related questions of the probability of hearing the VWS (as a factor in estimating how independent the VWS can be) and factors which should be considered in designing the VWS messages for high vehicle noise environments. Moreover, if the VWS is to be used in combination with the existing warning devices, the relationship between warning systems must be established to aid in integrating the new system into a composite system including the old devices.

C. APPROACH

1. Five Parallel Studies

This study was concerned with six Army aircraft (UH-1B, UH-1D, AH-1G, CH-47, CH-54, and OV-1). The UH-1B and UH-1D are very similar helicopters; while differences exist between these vehicles (such as crew/cargo space and external appearance), the basic systems, emergencies, and responses which the pilots would make to emergencies are essentially identical. All the other vehicles are very dissimilar. Consequently, this study was comprised of five parallel sub-studies conducted for each of five different vehicle types. Because the methods and techniques described in the following chapters were performed for each vehicle type, five sets of analyses and recommendations have resulted.

2. Information Requirements Analyses

A number of independent analyses was performed to aid in achieving the objectives of this study. The missions were analyzed and recorded to serve as a background of experience and information. Each of the emergencies was studied for each vehicle and diagrammed in the form of operational sequence diagrams (OSDs). Based on these data, a task analysis was performed for each emergency; this information provided

the basis to determine the information required by the pilot for each emergency and task differences that affect the determination of the priority sequence. A priority sequence was established for each vehicle in an independent fashion based on considerations of the pilot's task in confronting each emergency. Analyses also were performed to highlight specific needs for simultaneous presentation of messages for combined failures (instead of two messages in sequence), and the dependence of VWS messages on the phase of the mission during which an emergency occurs.

3. Pilot Information Surveys

Pilot information surveys were conducted for use in conjunction with the previous information requirements analyses. The information requirements analyses were based on analysis of task differences. These analyses were based on vehicle technical manuals and on information provided by pilot interviews. For example, the mission analyses and OSDs were based on information derived from, and verified by, pilots. However, it was desired to collect information from pilots for use in verifying message content and priority sequence recommendations and in determining the degree of user acceptance that could be expected from the results of this study. Consequently, a questionnaire was administered to a total of 180 pilots experienced in each of the vehicles concerned in this study. As part of this questionnaire, the pilots indicated a priority sequence, requirements for simultaneous presentation, mission dependence, recommendations for VWS message words, possible visual displays to be removed, and answered a number of general questions related to the objectives of this study. The results of the pilot information survey were carefully compared to the results of the information requirements analyses in forming the recommendations of this study.

4. Accident statistics

Accident statistics were collected for each of the five vehicle types to reflect on the accident-prevention capability of the VWS. The statistics collected were related to each of the proposed voice-warning messages as a measure of VWS coverage.

5. Cockpit Integration

The cockpit integration analyses conducted included examination of each visual display on the instrument panel of each vehicle to determine if it was redundant with any of the VWS messages. The VWS was considered in association with the expected high-noise environments, and a number of considerations were given to design of the VWS as it must function with high noise and in combination with other sources of warning information.

6. Message Content Analysis

A message content analysis was conducted to aid in the selection of messages that were maximally informative, easily discriminable, and capable of eliciting rapid response. As part of the pilot information survey, the pilots were requested to recommend a number of words for use in VWS messages. These words were used in a word discrimination test to provide guidance to message development efforts. After a composite list of messages was developed for all vehicles, numerous message-generating criteria were examined and alternative lists of messages were prepared. Subsequently, the words in these lists were tested in an empirical word discrimination study.

7. Summary

The current study was based on a spectrum of analyses. Study-team analyses concentrated on task variables associated with use of the VWS; pilot information analyses provided operational experience and user preferences. The recommendations that result are a compromise between the viewpoints impinging upon the study, with an attempt to optimize the VWS within the design freedom available.

D. BACKGROUND INFORMATION

The study performed was basically analytical in nature, with few empirical components. Consequently, the results of the study depend largely on the nature of the available information. In addition to the data collected through the efforts described in the previous subsections, a great deal of information was available in the published literature. Some of this literature, such as reports providing information on the effects of high noise, are summarized elsewhere in this report. Other literature (e.g., Refs. 2, 3, 4, and 5) was used very extensively, providing detailed guidance to this investigation. For example, a number of the techniques employed in this study were based directly on the recommendations in Ref. 5. A number of documents provided specific information on the VWS (e.g., Refs. 6, 7, and 8).

In addition to the published information, much information was collected through informal communication. For example, a number of informative discussions were held with members of the U.S. Army Board for Aviation Accident Research, U.S. Army Test Board, and Combat Development Command.

Air Force VWS. Because the Air Force has used a VWS in numerous flight vehicles for a number of years, trips were taken to collect information that may be relevant for the current study. At Norton Air Force Base, for example, considerable information was received relevant to

a questionnaire survey conducted on the B-58 VWS (Ref. 9). At Wright-Patterson Air Force Base, considerable information was available with respect to general design advice, methodology, and specific results. For example, with regard to the current VWS application, it is interesting to note that Air Force personnel voice the following opinions:

(1) The use of a female voice is recommended, but selection should be guided by the spectrum and intelligibility of the voice.

(2) Because the female voice is so distinctive, there is no need for an alerting signal to precede the voice messages as is usually specified. Because the alerting signal is not necessary, it contributes an unnecessary delay before information is transmitted to the pilot.

(3) Each message should begin with a different first word; once learned, the pilot's response can begin as soon as the first word is understood.

(4) Many tricks can be employed to extend or alter usual VWS operation (e.g., the logic is flexible, a method exists for increasing the number of channels of recording if needed, and, if a particular sensor tends to give brief spurious outputs, this can be cured by recording a soundless space on the tape before the message begins).

III. GENERAL VEHICLE INFORMATION

This study of voice-warning systems is concerned with six different aircraft: five helicopters (UH-1B, UH-1D, AH-1G, CH-47, and CH-54) and one fixed-wing aircraft (OV-1). Because each of these vehicles is quite different from each other, with the exception of the UH-1B and UH-1D, this study is comprised of five similar sub-studies. The UH-1B and UH-1D differ in fuselage and the arrangement of crew/cargo interiors, but because they are essentially identical from a mechanical and aerodynamic point of view the number and kinds of emergencies are the same. Consequently, for the purpose of this study of voice warnings, very little distinction is made between the UH-1B and UH-1D.

An overview of the vehicles considered in this study is provided by Table 1. Table 2 summarizes the few audio warnings currently available. This information is expanded in Appendix A for each vehicle. In addition to each vehicle description, photographs of each vehicle and its respective cockpit instrument panel are shown (Figures 1 through 11); lists of the current warnings given on the visual annunciator panel (Tables 3 through 7) are provided as reference information in Appendix A.

TABLE 1

Overview of Vehicles Considered in Voice-Warning Study

	UH-1B Iroquois (Huey) (Bell Helicopter)	UH-1D Iroquois (Bell Helicopter)	AH-1G Huey Cobra (Bell Helicopter)	CH-47 Chinook (Boeing Company)	CH-54 Skycrane (Sikorsky)	OV-1 Mohawk (Grumman Aircraft)
Mission	Supressive fire for troop helicopter escort and off loading. Nine-seat maximum (2 crew, 7 troops); or 3 litters, 2 sitting casualties, and medical attendant; or 3000 pounds freight.	Tactical transport. Seats 12 to 15 (crew and 12 troops); or six litters and medical attendant; or 4000 pounds of freight.	Attack and suppressive fire. Tandem, two seats.	Very heavy aerial fire support or medium transport. Can carry: several types of missile systems with launch crews; tube-type artillery weapons with crews; fuel; ground vehicles; high-density cargo; command and control centers; and full rifle platoon of 44 combat-equipped troops.	Hauling cargo and troops in van. Can be used for: troop transport (68 seats); mine sweeping; cargo and missile transport; and antisubmarine or field hospital operations.	Observation aircraft
Status	Operational; first flight (UH-1A) in 1956 as casualty evacuation transport.	Operational; in service since June 1963.	Initial production; first flight in 1965.	Operational; first flight in 1961 as medium tactical transport; armed version sent to Viet Nam in 1966.	First three flew in 1962	Operational; OB-1A, -1B, -1C, and -1E versions.
Speed (mph)						
Maximum	130 (clean)	138	190 (sea level to 3000 feet)	135 (clean)	117	297 (1B); 308 (1A and 1C).
Cruise	108 (clean)	135	149 (sea level)	110 (armed)	109	304 (1A); 275 (1B); 297 (1C).
Fuel capacity (U.S. gallons)	165	220	--	--	452 (each of two tanks)	--
Hover ceiling (feet)	16,880 (IGE) 12,700 (OGE)	18,200 (IGE) 14,000 (OGE)	16,000	6000 (OGE)	9700 (IGE) 4700 (OGE)	--
Service ceiling (feet)	16,700	22,000	--	--	10,500	30,000
Combat radius (nm)	93	--	250+	115	95+	705 (1A); 615 (1B); 665 (1C).
Rate of climb (feet per minute)	2350	2350	1990	--	1400	2950 (1A); 2350 (1B); 2670 (1C).
Propulsion	Lycoming T-53-11; turbo-shaft, 1100 shp (maximum).	Lycoming T-53-13; 1400 shp.	Lycoming T-53-13, turbo shaft, 1400 shp.	Two Lycoming T-55-7; turbo-shaft, each 2650 shp.	Two Pratt & Whitney JFTD 12A-1, gas-turbine, each 4050 shp.	Lycoming T-53-L-7; turbo-prop, 1150 shp.

TABLE 1 (continued)

	UH-1B Iroquois (Huey) (Bell Helicopter)	UH-1D Iroquois (Bell Helicopter)	AH-1G Huey Cobra (Bell Helicopter)	CH-47 Chinook (Boeing Company)	CH-54 Skycrane (Sikorsky)	OV-1 Mohawk (Grumman Aircraft)
Rotor systems	Two blades; main rotor blade diameter of 44 feet.	Two blades; main rotor blade diameter of 48 feet.	Two blades; main rotor blade diameter of 44 feet.	Dual tandem; three-blade rotors, fully articulated; main rotor diameter of 59 feet.	Sikorsky S-56; six blade, fully articulated, main rotor.	--
Armament/armor	Various, including: M-16, four 7.62mm guns and two 7-tube launchers for 5000-meter range, 2.75-inch rockets; M-5, nose turret 40mm grenade launcher for 2000-meter range; M-22, six wire-guided SS-11 anti-tank missiles; M-3, two 24-tube launchers for 2.75-inch rockets; XM-21 (in development), two 7.62mm miniguns and two 7-tube 2.75-inch rocket launchers.	Various, including: XM-23, 7.62mm machine gun.	Various, including: XM-129, 40mm grenade launcher (interchangeable with XM-135 7.62mm minigun); XM-140, 30mm 360-degree fire (under fuselage) turret gun, six TOW anti-tank missiles (optically tracked and wire-guided) now in development. Armor includes six external hard points, two on each wing and two on fuselage. Extensive armor for crew and aircraft vital components.	One M-5 chin turret 40mm grenade launcher; two M-24A 20mm guns, one each side firing forward, two XM-15 Gatling 7.62mm guns or two XM-159 rocket launchers, each with 19 2.75-inch rockets, one each side firing forward; four guns firing out cabin sides and one out aft ramp (either M-2 50mm or M-60 7.62mm).	--	--
Dimensions						
Fuselage length (feet)	42.6	44.6	44.0	51	70.417	--
Overall length (feet)	53	53.9	52.9	--	88.5	41
Gross weight (pounds)	8500	9500	9500	31,000 (33,000 maximum)	38,000 (42,000 maximum)	--
Empty weight (pounds)	4519	4717	--	17,878	17,240	10,000 to 10,975 (depends on version)

TABLE 2

Current Audio Warnings

Current Audio Warning	UH-1	AH-1G	CH-47	CH-54	OV-1
Rotor rpm	Buzz	Oscillating		None	None
Crew alarm bell			Bell		

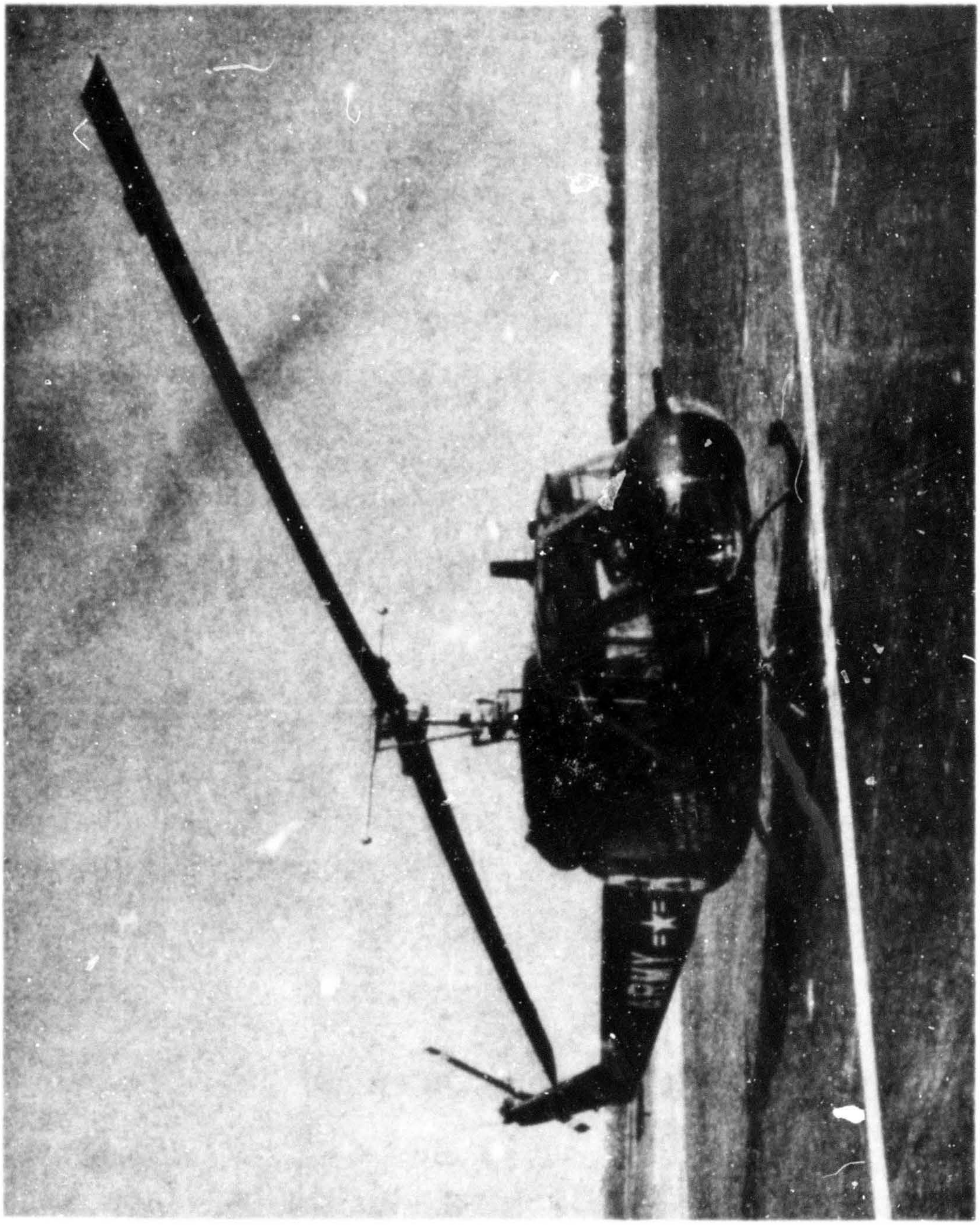


Figure 1. UH-1D (Huey) Helicopter

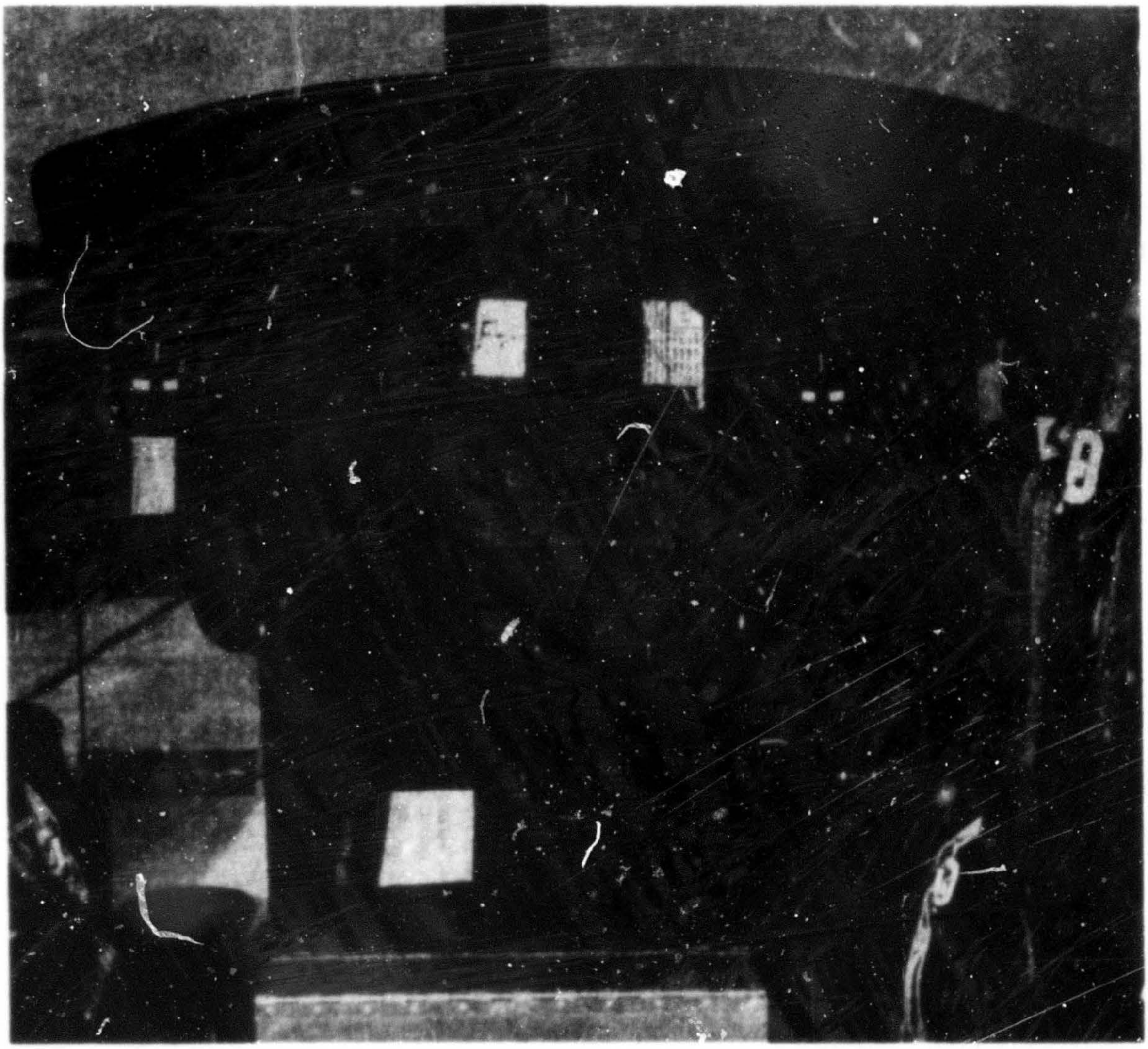


Figure 2. UH-1 Instrument Panel

Figure 3. AH-1G (Huey Cobra) Helicopter

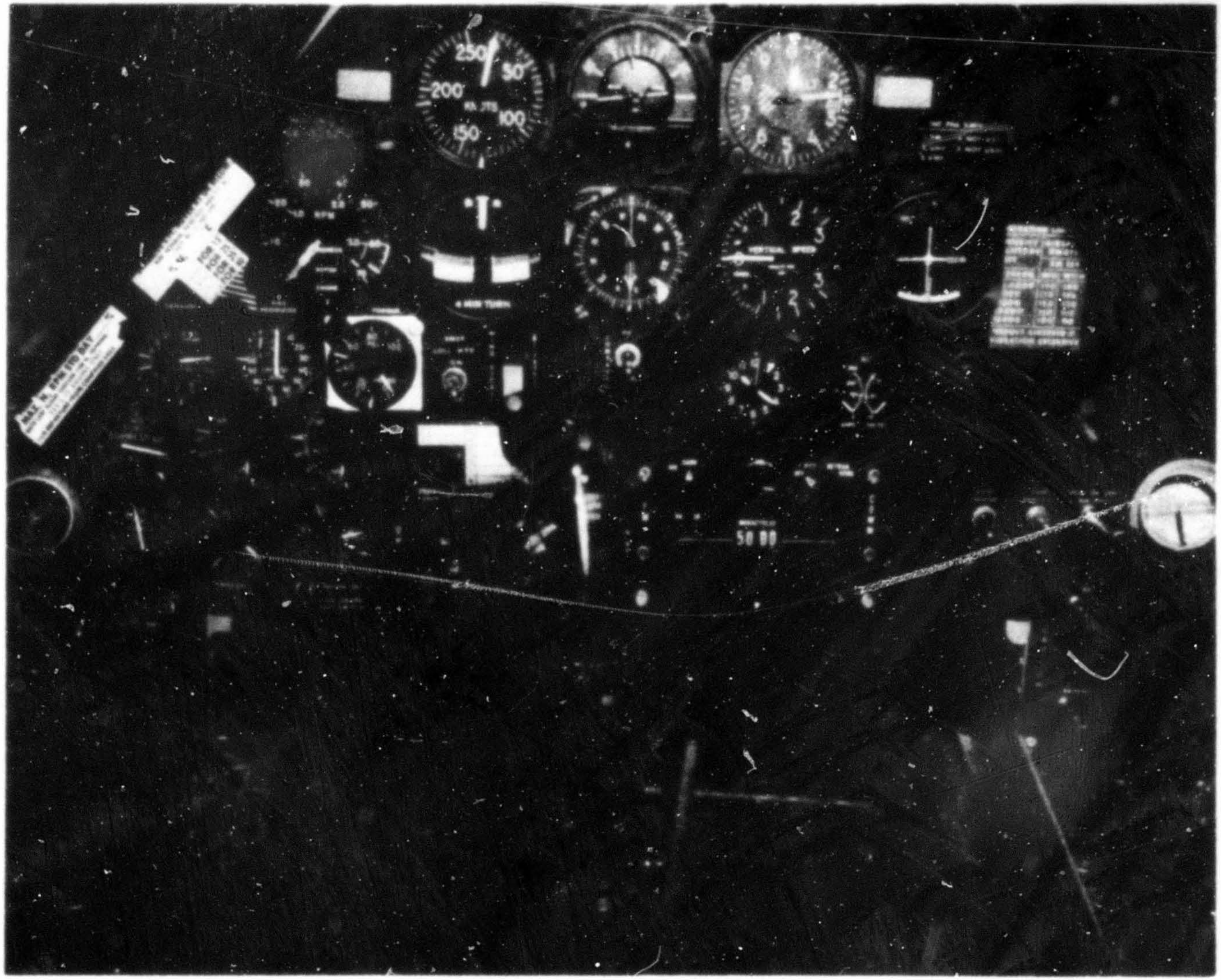


Figure 4. AH-1G Pilot's Instrument Panel

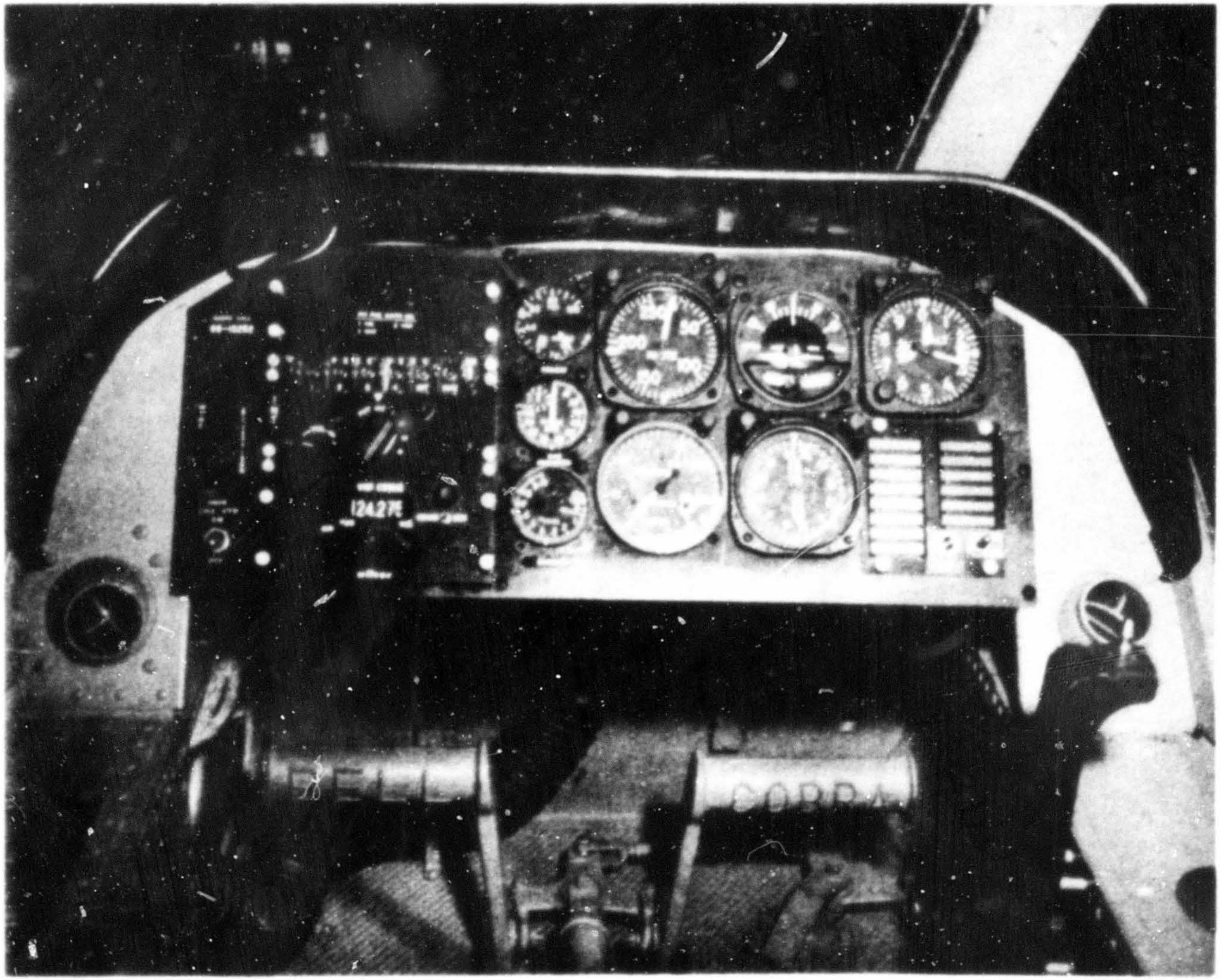


Figure 5. AH-1G Gunner's Instrument Panel

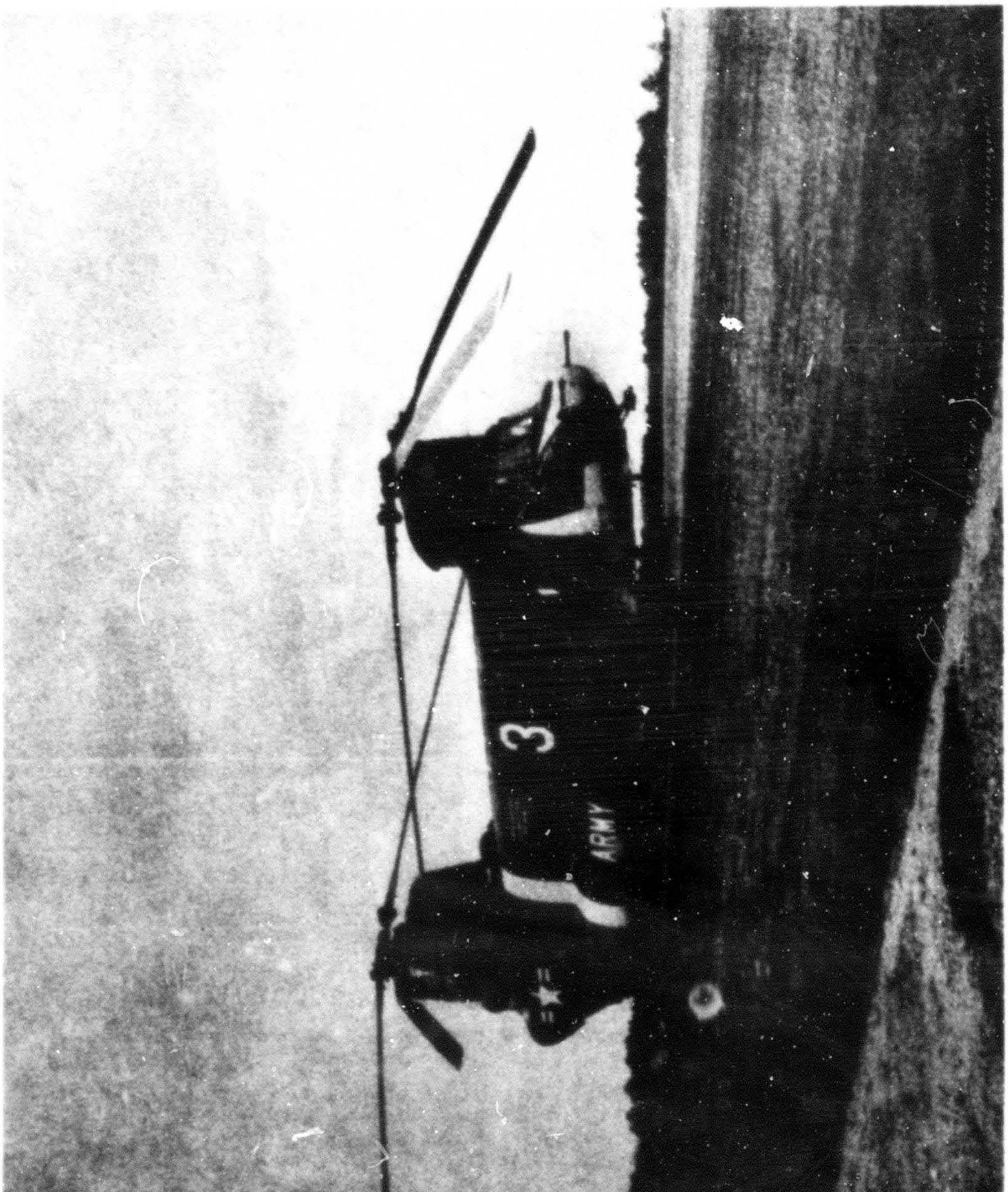


Figure 6. CH-47 (Chinook) Helicopter

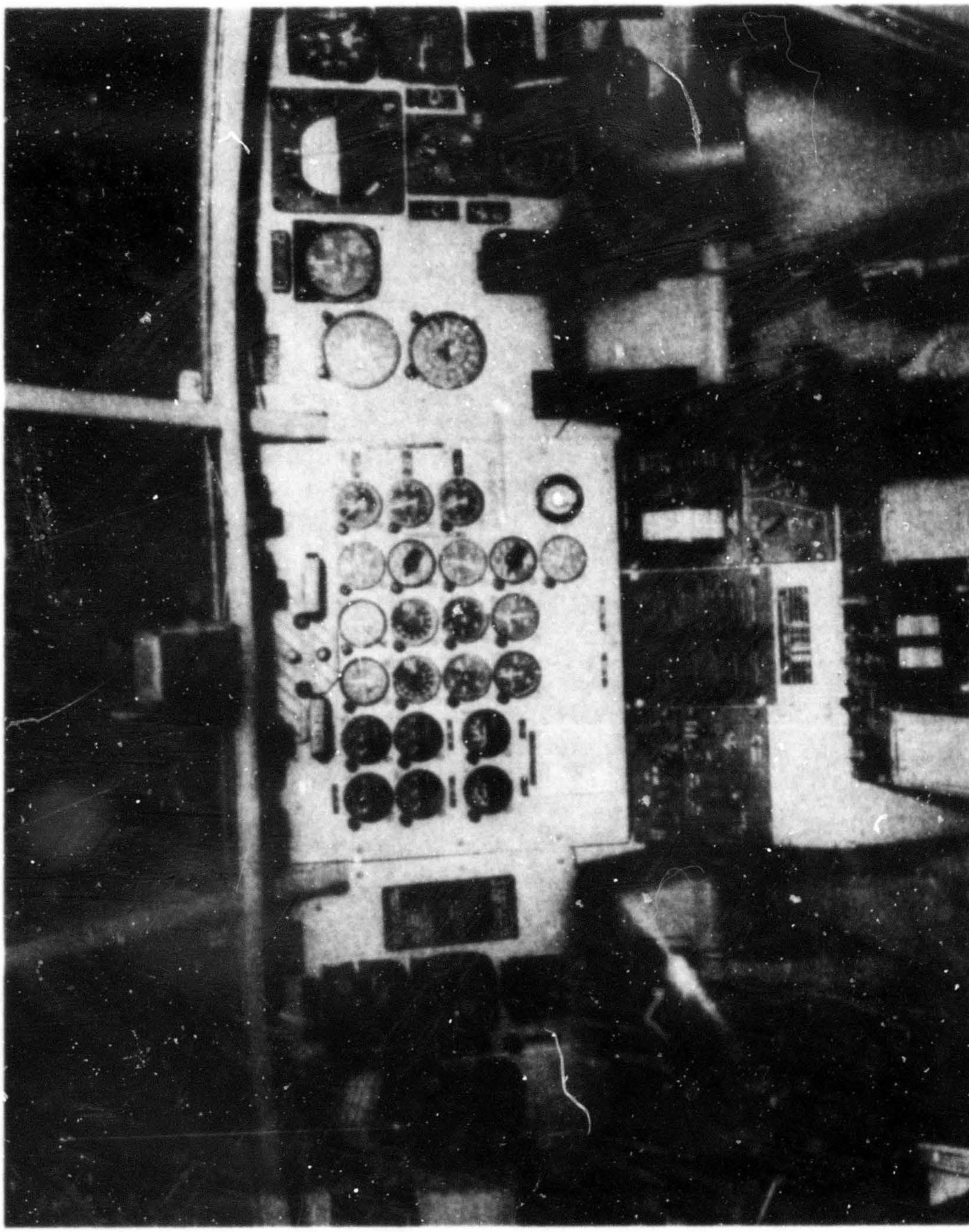


Figure 7. CH-47 Instrument Panel

Figure 8. CH-54 (Skycrane) Helicopter

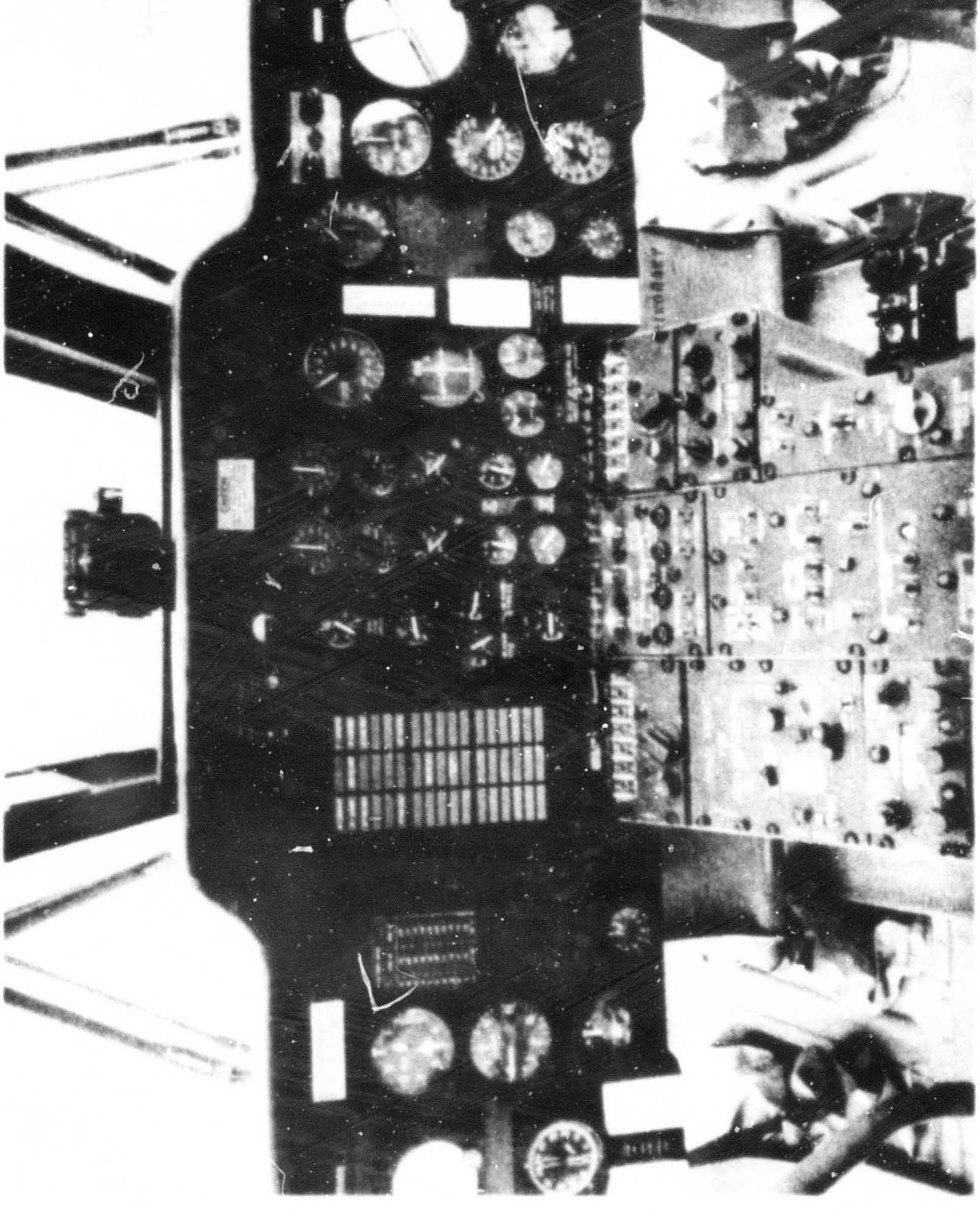


Figure 9. CH-54 Instrument Panel

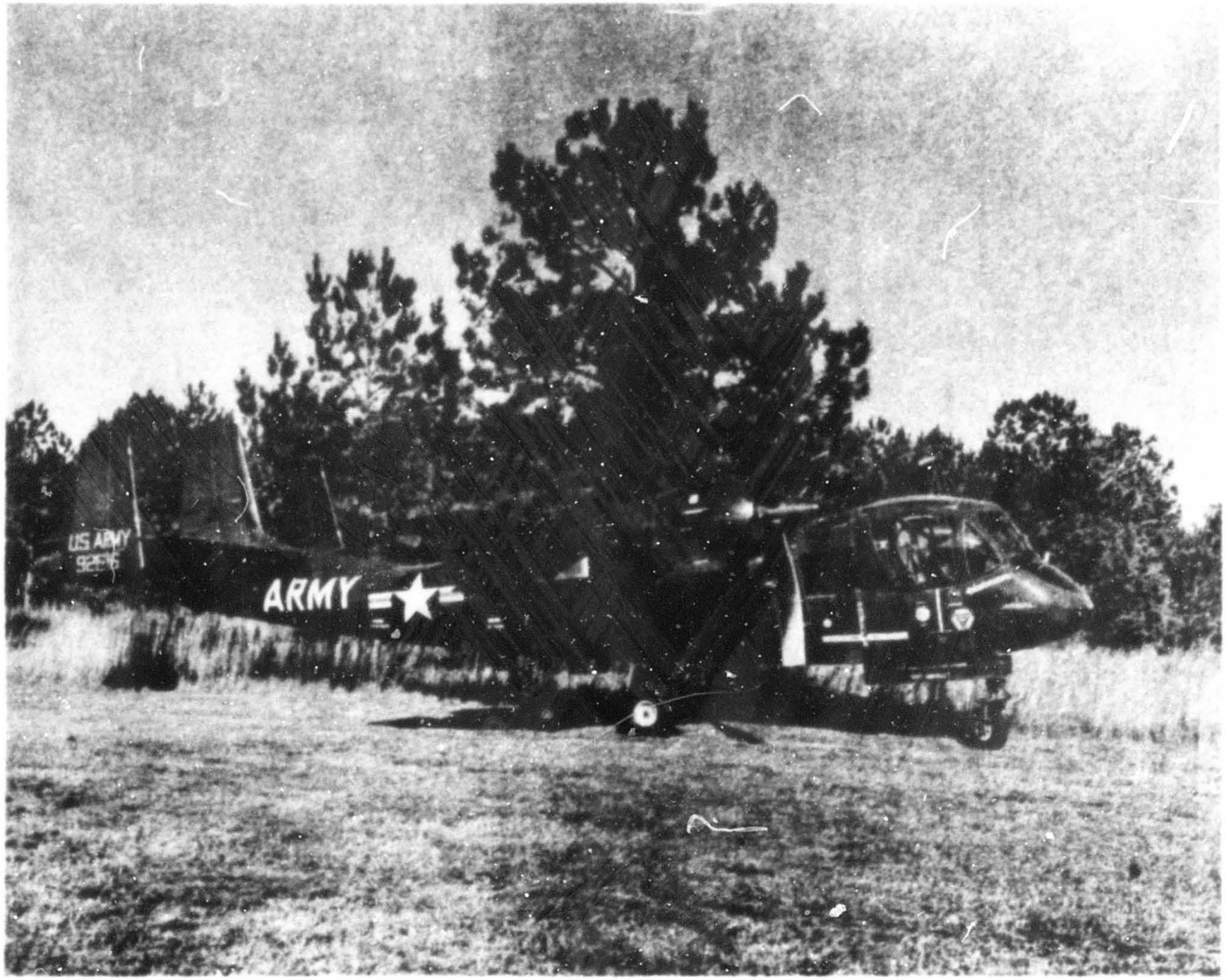


Figure 10. OV-1 (Mohawk) Aircraft

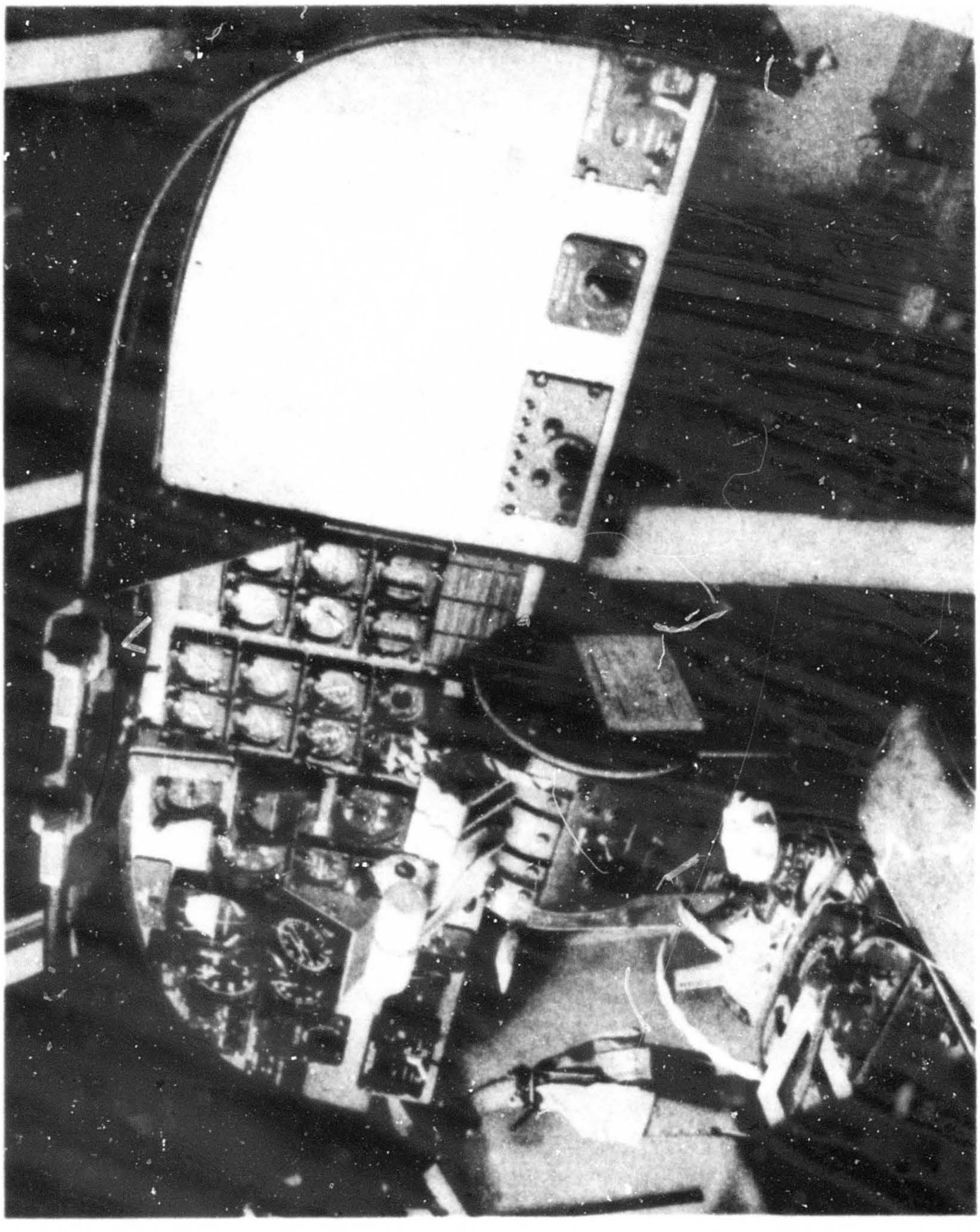


Figure 11. OV-1 Instrument Panel

IV. INFORMATION REQUIREMENTS ANALYSIS

To gain detailed familiarity with each vehicle, numerous analyses were conducted. The analyses in this chapter discuss the missions and tasks involved with emergencies in each of the several vehicles. For proper design of the messages for the voice-warning system (VWS), it is necessary to organize the messages in a priority sequence and select the information to be presented for each message. Additionally, it is necessary to ensure that all emergencies, and combinations of emergencies, are considered.

To organize the information needed for VWS design in an easily usable form, the following analyses were conducted: (1) mission analysis, (2) operational sequence diagrams, (3) task analysis, (4) priority analysis, (5) analysis of requirements for simultaneous presentation, and (6) analysis of mission-dependent emergencies. These analyses represent the best available information from Army technical manuals, pilot's checklists, manufacturers' manuals, operational pilots, instructor pilots, flight test pilots, Army engineers, and manufacturers' engineers.

A. MISSION ANALYSIS

The mission analyses were conducted to relate potential emergencies to the mission context; i.e., (1) the dependence of emergency pilot tasks on mission phase, (2) the consequences which may result, (3) the parts of the profile where the pilot's eyes would be occupied outside the cockpit, (4) the auditory load on the pilot, and (5) the estimation of the total task context and environmental factors. In short, the mission analyses were conducted to ensure the relevance of the current study for VWS and to form a background for subsequent analyses specific to VWS design. The mission analyses were, therefore, conducted only to the depth required to establish a context for this study and were tailored to the requirements for the analysis of emergency tasks.

An example of the mission analyses conducted is shown in Table 8. Table 8 shows only a small segment of the analysis conducted for one vehicle. A set of generic mission phases were defined for each vehicle, which is believed to be a comprehensive set of the unique segments of missions performed. These generic segments were then placed in a sequence to form a single mission which is comprised of all the components which form operational missions. As may be seen in Table 8, the analyses include definition of the flight operations, base operations, and support activities.

TABLE 8

An Example of a Section of the Mission Analysis for the CH-54 Helicopter

Description	Flight Operations	Base Operations	Support Activities
Hover over cargo-release point	Pilot brings aircraft to hover 20 feet above ground		Ground crew stays clear of cargo area
	Once hover is established, aft operator lowers cargo to ground		
	Pilot watches ground crew and maintains hover		
	Copilot monitors instruments and communicates with ground		When cargo is firmly on ground, ground crew unhooks sling
Secure cargo hooks	Aft operator brings cargo hook back up and secures it		Ground crew signals aircraft that it can leave
Move off cargo to landing area	Pilot maneuvers aircraft off cargo		
	Copilot monitors instruments and performs communications		
	Aft operator and crew chief watch for other traffic		
Land aircraft	Pilot adjusts collective and cyclic to accomplish landing		Aircraft ground crew waits at stations

Method. In developing the mission analyses, a trial analysis was performed using the available Army and manufacturers' manuals. Then, experienced pilots at Edwards Air Force Base and Fort Rucker were interviewed. The missions then were simulated on the ground in the cockpit of the appropriate vehicle until all parties were satisfied with the final product.

At Edwards Air Force Base, interviews were conducted with one or two highly experienced pilots for the OV-1, UH-1, and CH-47 aircraft. At the time of these initial interviews, only one pilot had had flight experience in the AH-1G (Cobra). None of the pilots at Edwards Air Force Base had any experience with the CH-54 (Skycrane).

The experience levels for the OV-1, UH-1, and CH-47 aircraft varied from 500 hours to well over 1000 hours of flight time in each type of vehicle.

Pilots were interviewed individually by two interviewers. During the interviews, the pilot was asked to describe, in detail, the task that he would perform during the course of flying a specified mission. The final part of the interview period was devoted to asking the pilot to fully describe the emergency procedures for the particular aircraft. Each interview took approximately 1-1/2 hours.

In an effort to refine the mission and task analyses and to aid in completing the operational sequence diagrams (OSDs) of the emergency procedures, a visit was made to the Army Aviation School at Fort Rucker, Alabama. At this time, a great deal of information remained to be collected for the AH-1G (Cobra) and the CH-54 (Skycrane). Interviews similar to those conducted at Edwards Air Force Base were performed using at least two different pilots for each aircraft. The pilots for these interviews were instructor pilots who had recent operational experience in Viet Nam.

B. OPERATIONAL SEQUENCE DIAGRAMS

As an outgrowth of the mission analyses, detailed analysis was performed on each of the emergency tasks that might involve a voice warning. The VWS may be classified as an auditory display. It gives the pilot information upon which he is to take action; it is obvious that if the emergency tasks are urgent, the pilot's actions must be rapid and correct, and, therefore, the voice-warning information must be precise and comprehensive.

The OSDs graphically portray the pilot tasks required by each potential emergency. These diagrams show the flow of information (transmissions, use, and storage), the decisions made, and actions taken by

the pilot. An example of the OSDs generated is shown in Figure 12. It may be seen that these diagrams show all the essential elements and events which comprise the successfully executed emergency. Consequently, these diagrams form an excellent basis for the current VWS study.

Potential additional warnings. OSDs were generated for all critical emergencies that may occur in each vehicle. As a result, it was noted that, for some emergencies, the pilot is not warned via the visual annunciator panel and, for other emergencies, no sensor exists to give the pilot an indication in any form that a malfunction exists. For reference in this study, Table 9 shows a list of potential additional warnings that should be considered for inclusion in the VWS.

C. TASK ANALYSIS

The OSDs give an excellent description of each emergency, but the requirements of the VWS design pose the need for interpretation of the tasks shown in the OSD. Moreover, assuming that the purpose of the VWS is to alert the pilot to an emergency and to give him enough information to make the correct response rapidly enough, much of the detailed response information shown in the OSDs is superfluous for present purposes. Consequently, the task analyses shown in Tables 10 through 14 in Appendix B were performed; these tables snow all the essential task information contained in the OSDs and additional information for VWS design, based on analysis of the emergency tasks.

Each task analysis shows the perceptual requirements, the pilot diagnostic problems, the alternative response options, and the stimulus/response relationships.

1. Perceptual Requirements

It is important to VWS design to know the information already available to the pilot. In some cases, an abundance of cues currently is available so that an additional warning in auditory form is highly redundant (e.g., single-engine failure in the OV-1); in other cases, no information currently is available, making the voice-warning message unique and desirable. In many cases, considerable information is available to the pilot, but it exists in scattered sources, requiring the pilot to waste valuable time integrating the information (or requires the pilot to spend considerable time scanning the instruments to detect the failures when they occur).

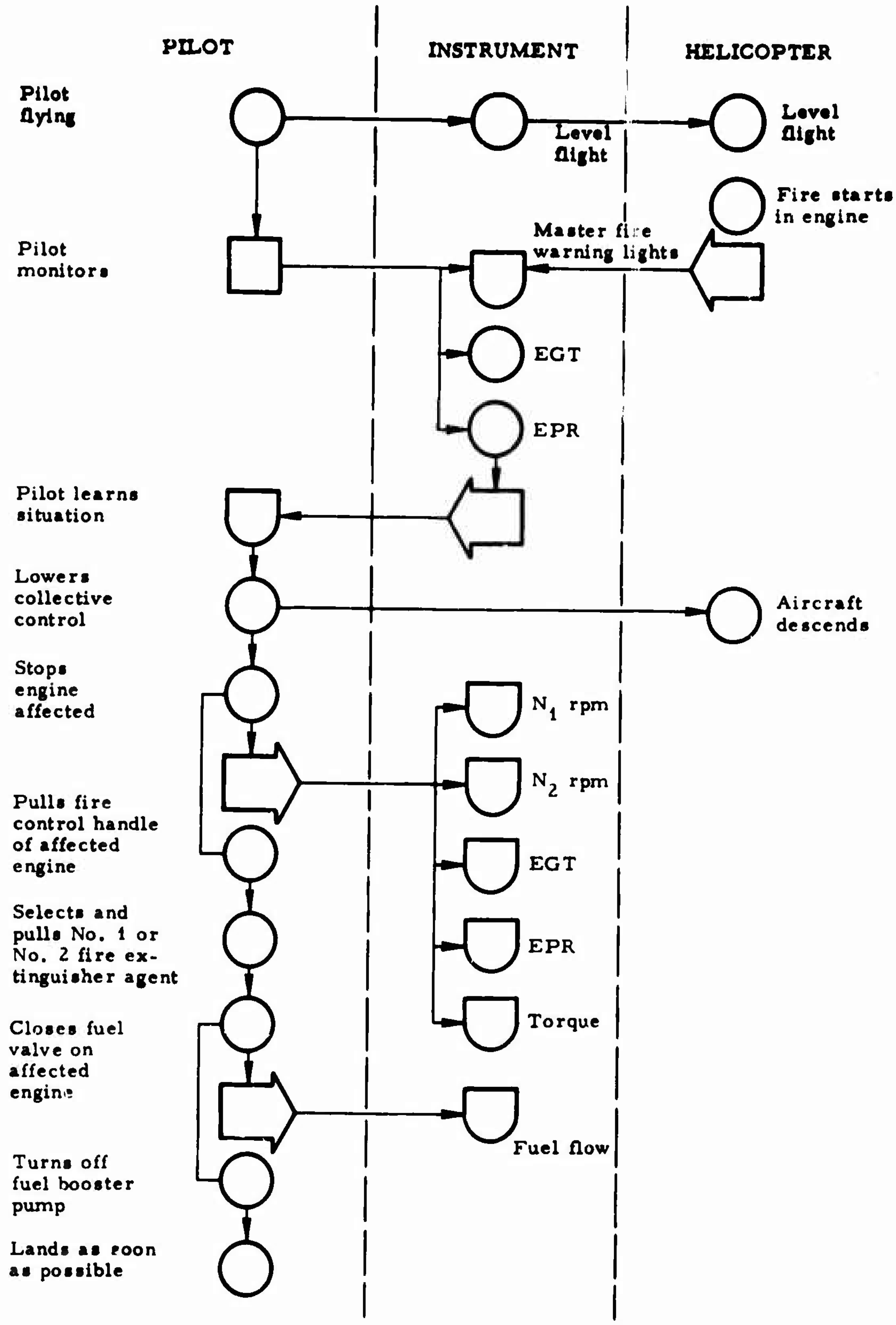


Figure 12. Example of an Operational Sequence Diagram—Engine Fire in Flight (CH-47)

TABLE 9

Potential Additional Warnings for the UH-1, AH-1G, CH-47, CH-54, and OV-1 Aircraft

Aircraft	Potential Warnings
UH-1	Tail rotor failure Fuselage fire Electrical fire Flight control system failure Over gross weight
AH-1G	Tail rotor failure or loss Tail pylon failure Fuselage fire Electrical fire Wing stores fire Low ammunition Flight control system failure ECM warning Obstacle clearance Gunfire detection
CH-47	Fuselage fire Electrical fire Longitudinal cyclic trim failure Normal engine beep trim switch failure Torque difference between engines Over gross weight Controls not centered for taxing
CH-54	Fuselage fire Electrical fire Automatic flight control system failure Pedal damper failure Hover stick malfunction Force gradient beeper trim system failure Torque difference between engines Over gross weight warning Loss of tail rotor
OV-1	Fuselage fire Electrical fire Wing fire Propeller failure Stall Oxygen pressure low ECM warning Obstacle clearance Gunfire detection

2. Diagnostic Elements

The diagnostic elements are essentially a summary of the information available to the pilot. Psychologically, these are the stimuli that should cause the pilot to generate the correct response.

3. Response Options

For many emergencies the pilot has more than one possible response. Ordinarily, the response option selected will depend on the extent of the failure, the altitude, distance to an air base, whether over friendly or enemy forces, etc.

4. Stimulus/Response Relationships

The stimulus/response relationships for a given failure are very important for VWS design. It is assumed that the VWS should give sufficient information for the pilot to take the correct action in a minimum amount of time. To minimize the amount of time to the correct response, it is desirable to present the pilot with a simple stimulus/response relationship; i. e., the stimulus (the VWS message) should indicate one and only one response (or initial response in a complex response sequence).

For many cases in the task analyses, it may be seen that simple stimulus/response relationships already exist. In these cases, the pilot may be informed of the nature of the failure or of the proper response to make; however, informing him of the failure gives him more precise information (since a number of failures may require the same response) and also allows him to determine the extent and speed of response appropriate to the specific requirements of the failure. Moreover, indicating the response rather than the nature of the failure may be dangerous; e. g., making pilot decisions without considering all circumstances that would be known only to the pilot at the time of the failure.

For other cases in the task analyses, the stimulus/response relationships are quite complex (e. g., engine failure). Organizing the information required by the pilot may be a great help to him; for example, informing him that he has lost an engine may greatly speed his response compared to the situation when instead, the pilot is sequentially informed that EGT is high, N_1 rpm is low, etc. His response speed may be further improved by indicating which engine has failed rather than requiring him to interpret the engine instruments to gain this information.

The stimulus/response relationships are shown in the task analysis tables in diagram form so the complexity is easily seen (Tables 10 through 14). Where the complexity is great, particular attention to simplification in the VWS design, via the proper selection of VWS messages, must be made.

D. PRIORITY ANALYSIS

The VWS incorporates a priority-sequence logic which is an extremely important consideration in the current study. If only one failure occurs at a time (i. e., only one voice-warning message tape is played), then the priority logic has no effect. However, if two failures occur simultaneously, the priority logic determines which message will be heard first by the pilot. Only when the pilot overrides the VWS or corrects the highest priority message will the lower priority messages be heard. Thus, an important question is: If multiple failures occur, which failure should the pilot be informed of first?

A paired-comparison technique was used to gain information relevant to VWS message priority. The technique considers only two failures at a time. It is believed highly improbable that more than two failures will occur at a time unless an entire system fails (causing a number of related messages to be initiated), but the major system warning appearing first will make the other related messages unnecessary. In the paired-comparison technique, each failure is considered in combination with every other failure; a decision is made with regard to which failure should be heard first. Table 15 shows an example of the worksheet used for this analysis. For each comparison, the selection of which message should be heard first and the reason for the selection is recorded. The priority analysis, as depicted in Table 15, was performed for each vehicle and for each possible combination of failures.

Numerous reasons were used to order the failures in a priority sequence. For the purposes of this analysis, the selections were made almost entirely on differences in the tasks posed by different failures. Initially, it was assumed that the differences in tasks would be most critical, and that differences such as ultimate consequences of a failure would be important only in extreme cases; however, other data would be collected on message priority elsewhere in the current study (in particular, the pilot information survey would yield directly relevant results). Hence, the emphasis at this point in the study was on task differences. The reasons used are as follows:

(1) One failure requires much more rapid response than the other. If a failure requires very rapid response, it should be attended to before a failure for which the response time is not critical; therefore, the message warning of the rapid-response failure should be presented first.

(2) One failure can wait until the other is attended to. If the pilot is warned of one failure at a time, it is possible he may not be aware of the second failure until he responds to the first and then overrides the VWS. If one failure can

TABLE 15

An Example of a Paired-Comparison Priority Analysis for the CH-54 Helicopter

Comparisons		Reasons	Comments
X Transmission oil pressure	_Transmission oil temperature	Transmission oil pressure is more important; high oil temperature can be tolerated.	Good possibility for both problems to occur at same time.
X Transmission oil pressure	_Intermediate transmission oil pressure	Main transmission more important since flight can continue with failure of intermediate transmission	
X Transmission oil pressure	_Fuel low	Transmission more critical and requires most immediate response	
X Transmission oil pressure	_Chip detector	Both are important, but pilot would respond to transmission oil pressure first	
X Transmission oil pressure	_First stage tail rotor servo	Pilot would respond to low transmission oil pressure first	
X Transmission oil pressure	_Fuel boost pump failure	Pilot would respond to low transmission oil pressure first	
X Transmission oil pressure	_Engine fuel control malfunction	Due to possible consequences, pilot would respond to low transmission oil pressure first.	
X Transmission oil pressure	_Free turbine N_2 flex cable failure	Due to consequences, pilot would respond to low transmission oil pressure first	
X Transmission oil pressure	_Fuel contamination	Transmission oil pressure requires first response	
X Transmission oil pressure	_Utility hydraulic system failure	Transmission oil pressure requires fastest response	
X Transmission oil pressure	_Automatic flight control failure (AFCS)	Due to consequences, pilot would respond to low transmission oil pressure first	
X Transmission oil pressure	_Electrical power system failure	Transmission oil pressure requires fastest response	
X Transmission oil pressure	_Electrical failure (d-c)	Transmission oil pressure requires fastest response	
X Transmission oil pressure	_Rotor speed abnormal	Due to consequences, pilot would respond to low transmission first	
X Transmission oil pressure	_Overtorquing	Overtorquing is usually momentary whereas low transmission oil pressure is continuous and more critical in consequences	
X Transmission oil pressure	_Torque difference between engines	Low transmission oil pressure is more serious in consequences	
X Transmission oil pressure	_Over gross weight warning	Low transmission oil pressure requires the first response	

wait for the other to be corrected, then it is clear which message should be presented first, regardless of the severity of the two failures.

(3) One failure is the primary emergency, while the other is a result of the primary emergency. In some cases, one failure may be considered the cause, and the other emergency may be considered the effect. For example, if the engine drives the pump for the hydraulic system, informing the pilot of the engine failure gives him more information than telling him of the hydraulic system failure first (of course, the pilot should know the hydraulic system is ineffective without telling him in this case).

(4) One failure can only occur during a particular mission phase and should have highest priority during this phase. If an emergency only can occur during a specific mission phase (e. g., wheels not down), it will not have an effect on the priority sequence during other portions of the mission. Consequently, the priority should be established as appropriate to the given mission phase.

(5) Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one of the emergencies. If two emergencies require the pilot to make the same response (e. g., land immediately), then it does not matter which failure is announced to him first. Nevertheless, more information may be conveyed by warning of one failure (for example, one of the failed systems may require the pilot to be alert for other impending danger, or may make the pilot aware that other systems also are impaired).

(6) One emergency is associated with so many natural cues that a voice warning is ordinarily redundant. A variety of visual, kinesthetic, auditory, or olfactory cues may accompany one failure; probably the pilot will become aware of this failure at the same time as the other failure is being announced to him via the VWS.

(7) One failure leads to much more serious consequences. If one failure could be fatal and the other is only minor, then it is clear which message should be announced to the pilot first. However, this reason was seldom used except for comparisons between failures which were obviously at opposite ends of the priority sequence.

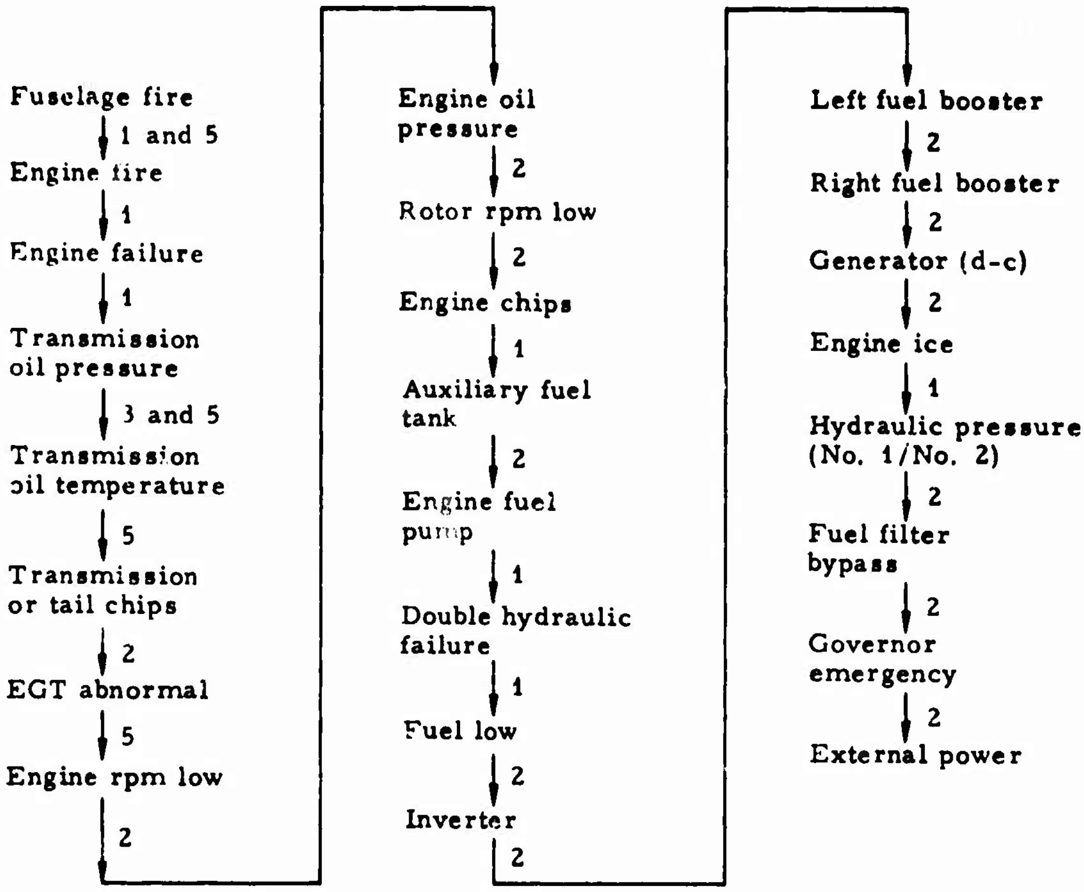
As a result of the paired-comparison technique, the failures were ranked in a priority sequence as shown in Figures 13 through 17. The arrows in these figures show the direction of priority in the ranking, from the messages to be heard first to those which would be heard last. It may be seen that the ranking in these figures is not always consistent. This is, however, understandable because the same reasons for ranking were not used throughout; A may be ranked higher than B, B ranked higher than C, and C ranked higher than A, but not for the same reasons in each case. In Figures 13 through 17, the arrows are accompanied by numbers corresponding to the seven reasons given previously, thereby showing the reason for ranking between adjacent failures in the ranking (the most difficult discrimination).

Although Figures 13 through 17 show a number of anomalies, they are left in this form to allow resolution with data collected elsewhere in this study.

E. REQUIREMENTS FOR SIMULTANEOUS PRESENTATION

It is conceivable that when two emergencies occur at the same time, the pilot may need to know about both to respond properly. The two failures may be highly related, requiring the pilot to modify the response that he would make to either one alone. Optionally, both failures may require very rapid responses, so that separate warnings may come too late. The VWS allows a possible solution: any two messages occuring together can cause a third message to be announced to the pilot; the third message can therefore indicate that a combined failure has occurred.

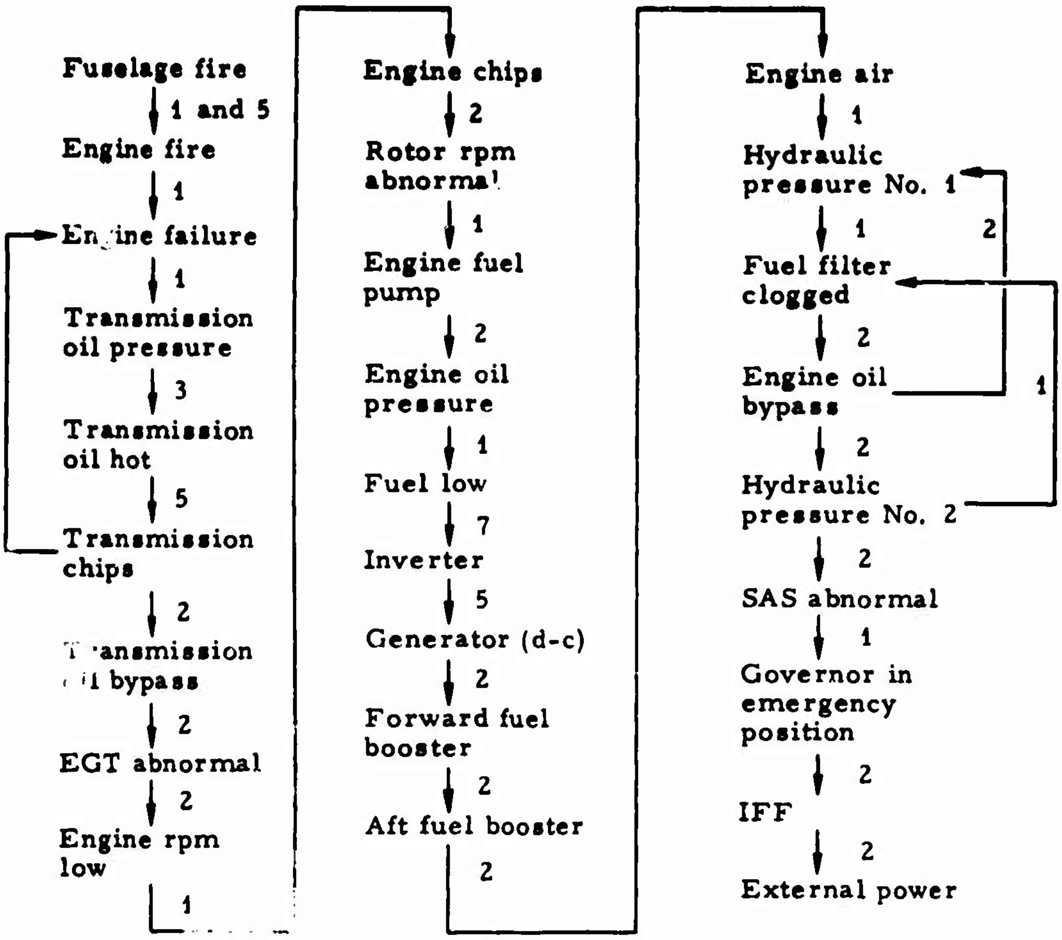
To investigate the possibility of a requirement for simultaneous presentation of multiple failures, combinations of failures were analyzed which either (1) require rapid response time, or (2) are closely related. The results of this analysis are shown in Tables 16 through 20. It may be seen that, in many cases, the response to multiple failures is the same; therefore, simultaneous warning is unnecessary. In other cases, the warnings are clearly related so that announcing one failure essentially negates the need for announcing the other failure; again, there is no need for a simultaneous warning. The only cases uncovered which require a simultaneous warning were those related to engine failure. When the engine fails, a number of subsystems fail, or parameters go out of tolerance, which would cause a number of VWS messages to simultaneously appear. This problem is solved if there is a separate message indicating engine failure.



NOTE: <u>Alternative Reasons for Ranking One Failure Over Another</u>

1. One failure requires much more rapid response than the other.
2. One failure can wait until the other is attended to (i.e., there is an immediate action to be taken for one failure).
3. One failure is the primary emergency, while the other may be a resultant of the primary emergency.
4. One failure can only occur during a particular mission phase, and should have higher priority during this phase, while the other failure should have higher priority for the rest of the mission.
5. Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one emergency first.
6. One emergency is associated with a number of visual, kinesthetic, auditory, or olfactory cues, so that ordinarily a voice warning is superfluous.
7. One failure leads to much more serious consequences.

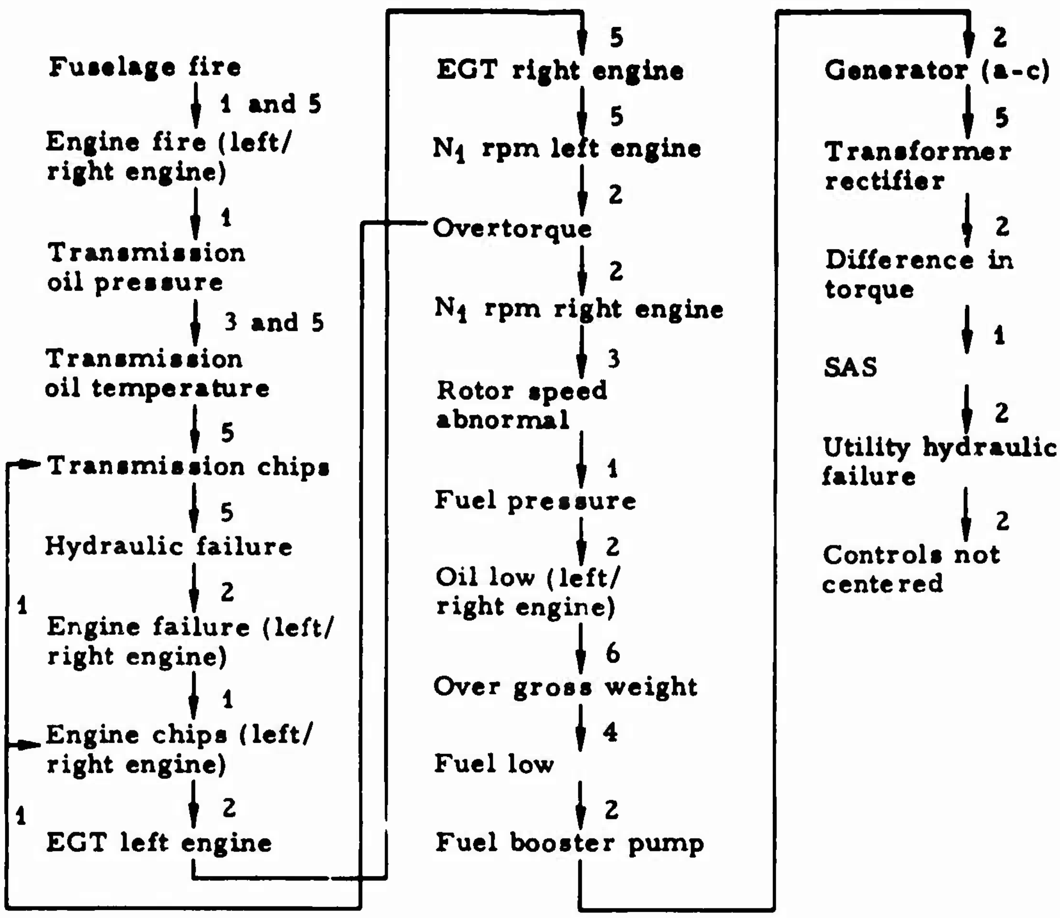
Figure 13. Results of UH-1 Ranking Analysis



NOTE: <u>Alternative Reasons for Ranking One Failure Over Another</u>

1. One failure requires much more rapid response than the other.
2. One failure can wait until the other is attended to (i.e., there is an immediate action to be taken for one failure).
3. One failure is the primary emergency, while the other may be a resultant of the primary emergency.
4. One failure can only occur during a particular mission phase, and should have higher priority during this phase, while the other failure should have higher priority for the rest of the mission.
5. Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one emergency first.
6. One emergency is associated with a number of visual, kinesthetic, auditory, or olfactory cues, so that ordinarily a voice warning is superfluous.
7. One failure leads to much more serious consequences.

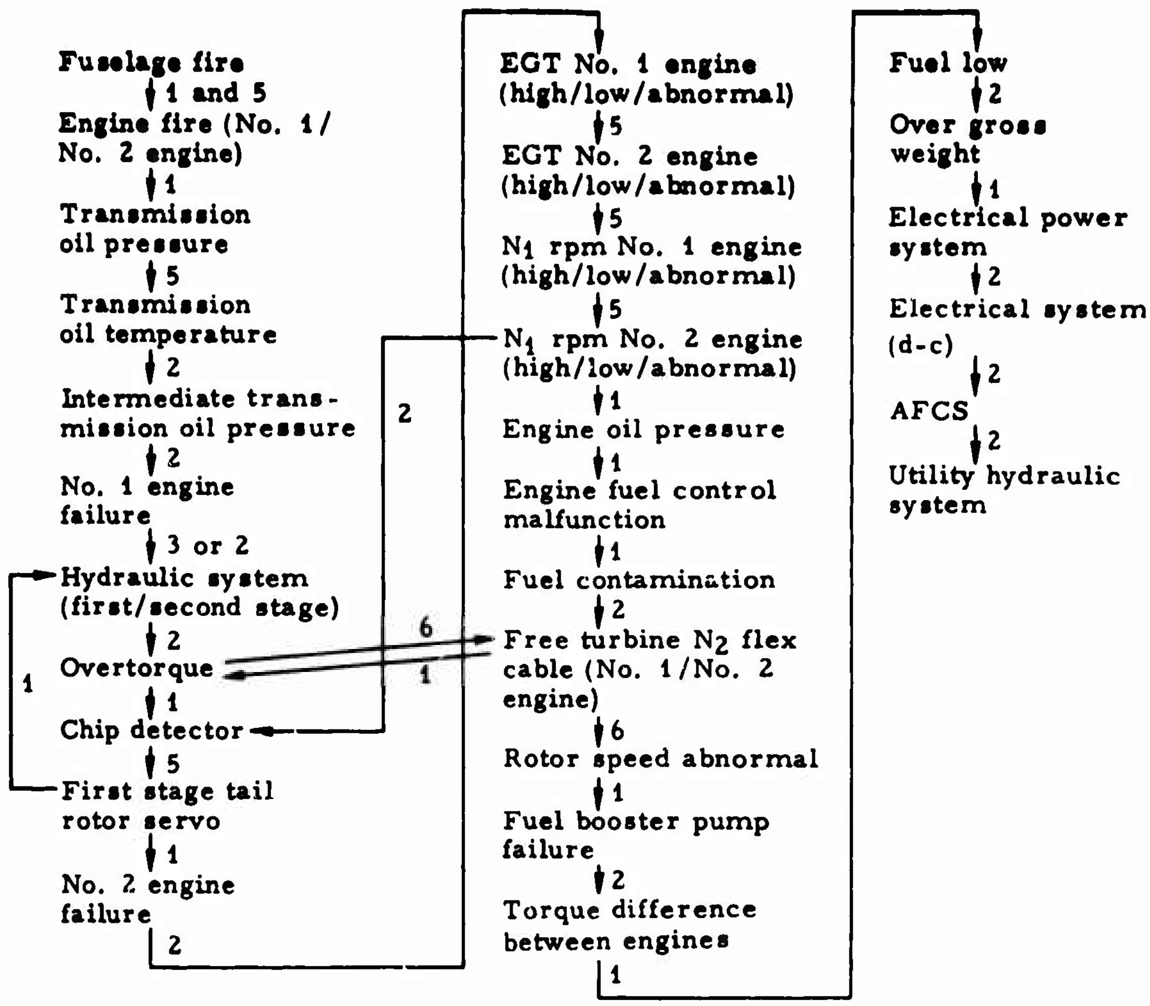
Figure 14. Results of AH-1G Ranking Analysis



NOTE: <u>Alternative Reasons for Ranking One Failure Over Another</u>

1. One failure requires much more rapid response than the other.
2. One failure can wait until the other is attended to (i. e., there is an immediate action to be taken for one failure).
3. One failure is the primary emergency, while the other may be a resultant of the primary emergency.
4. One failure can only occur during a particular mission phase, and should have higher priority during this phase, while the other failure should have higher priority for the rest of the mission.
5. Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one emergency first.
6. One emergency is associated with a number of visual, kinesthetic, auditory, or olfactory cues, so that ordinarily a voice warning is superfluous.
7. One failure leads to much more serious consequences.

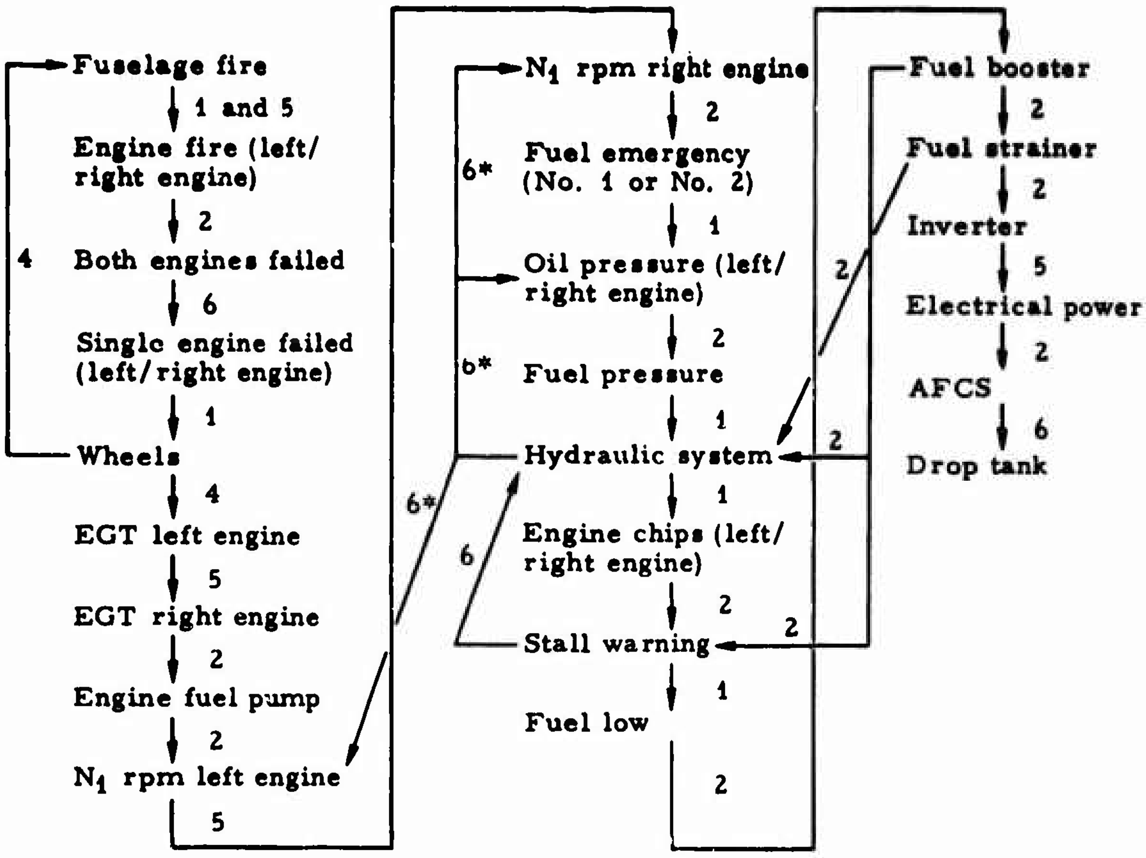
Figure 15. Results of CH-47 Ranking Analysis



NOTE: <u>Alternative Reasons for Ranking One Failure Over Another</u>

1. One failure requires much more rapid response than the other.
2. One failure can wait until the other is attended to (i.e., there is an immediate action to be taken for one failure).
3. One failure is the primary emergency, while the other may be a resultant of the primary emergency.
4. One failure can only occur during a particular mission phase, and should have higher priority during this phase, while the other failure should have higher priority for the rest of the mission.
5. Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one emergency first.
6. One emergency is associated with a number of visual, kinesthetic, auditory, or olfactory cues, so that ordinarily a voice warning is superfluous.
7. One failure leads to much more serious consequences.

Figure 16. Results of CH-54 Ranking Analysis



*Since the hydraulic system is used to operate the flaps and landing gear, the failure of this system assumes a high priority over several other emergencies during the approach and landing period of flight.

NOTE: Alternative Reasons for Ranking One Failure Over Another

1. One failure requires much more rapid response than the other.
2. One failure can wait until the other is attended to (i.e., there is an immediate action to be taken for one failure).
3. One failure is the primary emergency, while the other may be a resultant of the primary emergency.
4. One failure can only occur during a particular mission phase, and should have higher priority during this phase, while the other failure should have higher priority for the rest of the mission.
5. Both failures require essentially the same response from the pilot, but it is more informative to tell the pilot of one emergency first.
6. One emergency is associated with a number of visual, kinesthetic, auditory, or olfactory cues, so that ordinarily a voice warning is superfluous.
7. One failure leads to much more serious consequences.

Figure 17. Results of OV-1 Ranking Analysis

TABLE 16

Need for Simultaneous Presentation of Combined Features for the UH-1

Failure No. 1	Failure No. 2	Time to Respond* No. 1	Time to Respond* No. 2	Do Failures Require Different Response?	Are Failures Related?	Need Simultaneous Warning?	Comments
Transmission oil temperature	Transmission chip detector	B	B	No	No	No	Land immediately for both.
Fuselage fire	Engine failing	A	A	No	No	No	Land immediately for both.
Transmission oil temperature	Transmission oil pressure	B	B	No	Yes	No	Land immediately for both.

* A: Requires rapid response which takes precedence over all other activities
B: Requires quick attention, but there is time for double checking and diagnosis

TABLE 17

Need for Simultaneous Presentation of Combined Features for the AH-1G

Failure No. 1	Failure No. 2	Time to Respond* No. 1	Time to Respond* No. 2	Do Failures Require Different Response?	Are Failures Related?	Need Simultaneous Warning?	Comments
Transmission oil pressure	Engine oil pressure	B	B	No	No	No	Land immediately for both.
Engine oil pressure	Rotor rpm abnormal	B	B	Yes	No	No	Rotor rpm abnormal would not require immediate landing.
Engine out	Rotor rpm abnormal	A	B	Yes	Yes	No	Engine out would require immediate landing.
Rotor rpm abnormal	Transmission oil pressure	B	B	Yes	No	No	Transmission oil pressure would require immediate landing.
Chip detected	Transmission oil pressure	B	B	No	No	No	Land immediately for both.
Transmission oil temperature	Transmission oil pressure	B	B	No	Yes	No	Pilot will check both.

*A: Requires rapid response which takes precedence over all other activities
B: Requires quick attention, but there is time for double checking and diagnosis

TABLE 18

Need for Simultaneous Presentation of Combined Features for the CH-47

Failure No. 1	Failure No. 2	Time to Respond* No. 1	Time to Respond* No. 2	Do Failures Require Different Response?	Are Failures Related?	Need Simultaneous Warning?	Comments
Transmission oil pressure	Transmission oil temperature	B	B	No	Yes	No	Pilot will check both.
Transmission oil pressure	Transmission chip detected	B	B	No	No	No	Land immediately for both.
Torque difference between engines	EGT abnormal, No. 1 engine	B	B	No	Yes	No	EGT warning should alert pilot to torque difference.
Torque difference between engines	EGT abnormal, No. 2 engine	B	B	No	Yes	No	EGT warning should alert pilot to torque difference.
Torque difference between engines	N_1 rpm, No. 1 engine	B	B	No	Yes	No	N_1 rpm warning should alert pilot to torque difference.
Torque difference between engines	N_1 rpm, No. 2 engine	B	B	No	Yes	No	N_1 rpm warning should alert pilot to torque difference.

*A: Requires rapid response which takes precedence over all other activities
B: Requires quick attention, but there is time for double checking and diagnosis

TABLE 19

Need for Simultaneous Presentation of Combined Features for the CH-54

Failure No. 1	Failure No. 2	Time to Respond* No. 1	Time to Respond* No. 2	Do Failures Require Different Response?	Are Failures Related?	Need Simultaneous Warning?	Comments
Engine fire	Fuselage fire	A	A	No	Yes	No	Land immediately for both.
Engine fire	Transmission oil pressure	A	B	No	No	No	Land immediately for both.
Fuselage fire	Transmission oil pressure	A	B	No	No	No	Land immediately for both.
Fuselage fire	Transmission oil temperature	A	B	No	No	No	Land immediately for both.
Transmission oil pressure	Transmission oil temperature	B	B	No	Yes	No	Pilot will check both.
N_1 rpm, No. 1 engine	Torque difference	A	B	No	Yes	No	N_1 rpm low message will indicate torque difference.
N_1 rpm, No. 2 engine	Torque difference	A	B	No	Yes	No	N_1 rpm low message will indicate torque difference.
Engine failure	Rotor speed abnormal	A	A	No	Yes	No	Engine failure message indicates rotor speed abnormal.
Rotor speed abnormal	Overtorque	A	A	No	Yes	No	Overtorque message first indicates pilot should reduce engine torque.
Hydraulic system, second stage	EGT, No. 1 engine	B	A	Yes	Yes	No	Hydraulic system message first results in right response. Emergency may result in double hydraulic system failure.
Hydraulic system, second stage	N_1 rpm No. 1 engine	B	A	Yes	Yes	No	Hydraulic system message first results in right response. Failure may result in double hydraulic system failure.

*A: Requires rapid response which takes precedence over all other activities
B: Requires quick attention, but there is time for double checking diagnosis

TABLE 20

Need for Simultaneous Presentation of Combined Features for the OV-1

Failure No. 1	Failure No. 2	Time to Respond* No. 1	Time to Respond* No. 2	Do Failures Require Different Response?	Are Failures Related?	Need Simultaneous Warning?	Comments
Fuselage fire	Engine fire	A	A	No	No	No	Land immediately for both.
Fuselage fire	Wheels not down	A	A	Yes	No	No	Pilot would probably respond to wheels warning first so that a safe landing could be effected.

*A: Requires rapid response which takes precedence over all other activities
B: Requires quick attention, but there is time for double checking diagnosis

F. MISSION-DEPENDENT EMERGENCIES

Another consideration is the possibility that some failures may be quite critical in some portions of the mission, but unimportant in other parts. If the failures are mission-dependent, the priority sequence may need to change with mission phases.

Each failure for each mission was considered for possible mission-dependent features; the findings are summarized as follows:

(1) Near base. A number of emergencies may be treated differently if they occur during hover or just after takeoff.

   (a) If rotor rpm is low, the pilot would probably land the aircraft until sufficient rotor speed could be obtained.

   (b) Over gross weight should be detected quickly so that excess weight can be removed.

   (c) If fuel is low near a base, the aircraft would be landing for refueling; otherwise, the mission probably would be continued.

   (d) The pilots of the OV-1 might land rather than eject, if the fuselage or wings were on fire.

(2) Depends on power or airspeed. The response to an emergency, such as a tail rotor failure, will depend on the flight conditions prevailing at the time.

(3) At high altitude. At high altitude during cruise, the pilot may attempt to restart a failed engine, and his response to a fuel boost pump failure would be different.

(4) Miscellaneous failures. A number of failures would be too minor to abort the mission once well underway, but maintenance action might be taken if the failure was detected at the start of the mission.

(5) Strictly mission-dependent failures. It was found, however, that a number of emergencies normally will be important only during specific mission phases. On the ground, "a-c/d-c external power on" is of concern in the CH-47, but not at any other time. During approach, the "hydraulic system" and "wheels not down" warnings are very important in the OV-1, but otherwise are not critical. Only after landing are the "wheels dephased," "parking brake on," and "controls not centered" warnings important in the CH-47.

Consequently, while a number of emergencies are treated differently at different times, in most cases the emergencies are not clearly dependent on mission parameters. Where the pilot response to an emergency depends on mission parameters, it may be possible to design the VWS messages and priority sequence to aid pilot diagnosis. However, in most cases (except those which are strictly mission-dependent), differentiating the importance of an emergency or the nature of the response required would amount to making a decision about which only the pilot, at the time of the emergency, would have enough information to make a rational decision.

V. ACCIDENT STATISTICS

As additional information about required warnings or potential problems become available, statistics about aircraft accidents were collected. This information could serve as an aid in selecting the warnings which would be presented on the VWS.

Arrangements were made with the Statistical Branch (USABAAR) to collect statistics from the accident data bank maintained at Fort Rucker in punched-card form. The accident data were gathered for all vehicles concerned in this study for the following classes of accidents: major, minor, incident, forced landings, and precautionary landings. In addition, Equipment Improvement Reports (EIRs) references were included where pertinent. All statistical numbers for the classes of accidents were reported as a single total. Major accidents are those accidents which result in substantial damage to the aircraft, requiring more than 400 to 500 man-hours to repair. Minor accidents are those accidents which result in at least 100 to 250 man-hours to repair. Both of these types of accidents may involve crew fatalities or injuries. Incidents are those accidents which require 100 hours or less to repair. Forced landings are those accidents in which the pilot was forced to make an unplanned landing, but was able to effect the landing so that there was no damage to the aircraft. Precautionary landings are those accidents in which the pilot made a landing merely as a safety measure. EIRs are submitted by pilots as a means of getting improvements or changes in equipment which does not function desirably. It is an opinion tool which the Army uses to determine which parts of equipment need to be improved.

The accident statistics were requested by major system and, if meaningful, by subsystem; although further subdivision is possible, it did not appear that a further breakdown of the statistics would be desirable. The dates of the accident statistics were from 1 January 1960 through 1 November 1967.

1. Some Cautions

The statistics do not include data about battle damage because this is not considered accidental. In the instance of forced landings, precautionary landings, or incidents, the cause of the accident is known because the crew and aircraft survived; however, for major and minor accidents, the damage, injuries, or fatalities are often so severe that the cause of the accident is, at best, based upon supposition. In many major accidents, the true cause is never determined because of the lack of witnesses or the condition of the wreckage.

The number of accidents for each aircraft vary considerably, because of factors such as the total number of aircraft in the Army inventory, the length of time which the aircraft has been in operation, the amount of use, mission requirements, skill required, training requirements, etc. Thus, aircraft such as the UH-1 and OV-1 have relatively large numbers of accidents because these aircraft comprise a major portion of the Army's operational accident data. The data for the CH-47 and CH-54 aircraft are small, because these aircraft have not been in service very long nor do they comprise a very large percentage of the Army inventory. Accident statistics for the AH-1G were almost nonexistent, because the aircraft had just entered the operational inventory at the time these statistics were collected and it did not exist in large quantities.

The accident statistics do not present an indication of the number of false alarms which occurred during this period. These reports are probably combined in the totals attributed to precautionary landings or the number of EIRs for a particular component.

Accident statistics about the number of cases involving fire are extremely rare in the data; however, when compiling accident statistics, fire is often considered the result of an accident rather than the cause.

2. Discussion

The data provided by USABAAR are shown in Tables 21 through 25. In terms of numbers, the data for the UH-1, CH-47 and OV-1 do appear to be sufficiently large enough to be representative of these aircraft, but paucity of data for the AH-1G and the CH-54 aircraft reduce the usefulness of accident statistics.

The data for the UH-1 aircraft (Table 21) present several interesting results. The highest numbers of accidents reported are for the power plant (853), transmission (354), flight controls (197), hydraulic/pneumatic (153), instrument systems (147), and airframe/fuselage (125). In the case of the flight control system, it is debatable if a voice warning would be significant in reducing accidents because the failure is usually very obvious, and, also, there is a problem of sensing the failure early enough to provide the pilot ample time to take precautionary measures. The data indicate that engine failure warnings probably should be considered for inclusion in the VWS. The information is currently presented to the pilot by interpretation of his engine gages rather than by direct warning. The number of accidents reported for the transmission and hydraulic/pneumatic systems indicates that voice-warning messages for these two systems are quite important. The accidents attributed to the instrument systems reflect the malfunction of the display devices which the pilot uses in performing his flight task.

It is doubtful that a voice warning for these types of malfunctions would be feasible because of the many sensors required. The number of accidents for the airframe/fuselage part of the UH-1 indicates that some consideration should be given to providing a fire voice warning for this area of the aircraft.

One very surprising fact provided by the statistics for the UH-1, CH-47, or OV-1 is the relatively few accidents reported for fuel problems or from chip detection. These data seem to indicate that these problems are apparently not as frequent as one might suspect, based upon the number of visual warnings provided.

The accident data for the CH-47 seem to follow the same trend as the UH-1 although there are fewer numbers of accidents reported. The data reveal that the aircraft areas showing the highest frequencies of accidents are the transmission (105), power plant turbine (110), hydraulic/pneumatic (56), instrument systems (43), airframe/fuselage (24), and flight controls (24).

The OV-1 vehicle was the only fixed-wing aircraft in the study. The data indicate that the areas showing the highest incidence of accidents are engine failure (123), landing gear (40), propeller (32), hydraulic/pneumatic (30), and the airframe/fuselage (27). The landing gear accidents include the failure of any part of the landing gear or the failure to lower the landing gear; currently, a visual warning indicates to the pilot that his landing gear is not down and locked. The number of propeller incidents would seen to indicate that a voice warning would be warranted; however, the difficulty of placing sensors and the fact that the failure is normally very obvious to the pilot may reduce the requirement for a voice warning.

TABLE 21

UH-1 Accident Statistics

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Airframe/fuselage				125
Fuselage structure		Fuselage fire	2	
Fixed tail structure			1	
Wings/main rotor blades			15	
Helicopter tail cones			1	
Brakes				
Flight controls				197
Aileron			11	
Elevator			2	
Speed brakes			1	
Helicopter cyclic control system			84	
Helicopter collective control system			32	
Helicopter tail rotor control system		Tail rotor emergency	53	
Wings variable incidence			3	
Electrical/electronics				96
Fires			3	
Power system (d-c)		Electrical failure	40	
Power system (a-c)		Electrical failure	11	
Electronics system, radar/radio			28	
Fuel	20-minute fuel Auxiliary fuel low Fuel filter bypass	Fuel low Fuel pressure low Fuel contaminated		49

TABLE 21 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Ordnance				28
Hydraulic/pneumatic	Low hydraulic pressure	Hydraulic pressure low		153
Instrument systems				147
Stall warning system (stick shaker)			5	
Fire detection system		Fuselage fire Electrical fire Engine fire	16	
Rotor rpm dissipation indicator	Rotor rpm low or high	Rotor rpm abnormal	11	
Oil temperature		Oil hot	6	
Chip detector	Chip detector	Engine chip Transmission chip	8	
Master caution	Master caution	Check caution panel	1	
Landing gear				6
Auxiliary equipment				1
Power plant controls				9
Throttle control system			6	
Engine air cooling control		Engine air	1	
Air induction system			2	
Oil	Engine oil pressure low	Oil pressure low		11
Power plant				14
Power plants turbine		Engine failing Fire	15	853
01 to 13			752	
Unknown, but suspect			101	

TABLE 21 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Helicopter transmission	Low transmission pressure	Transmission pressure low		354
	High transmission oil temperature	Transmission temperature high		
Chip detector indicator	Chip detector	Chip detected		35

TABLE 22

AH-1G Accident Statistics

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Airframe/fuselage				
Fuselage structure		Fuselage fire	0	2
Brakes			0	
Flight controls				
Cyclic control system		Flight controls damaged	0	
Collective control system		Flight controls damaged	0	
Tail rotor control system		Tail rotor lost	0	
Electrical/electronics				
Power system (d-c)	Generator (d-c)	Generator (d-c)	0	
Power system (a-c)	Instrument inverter	Inverter failure	0	
External power system	External power	External power	0	
Electronics system (radar/radio)	IFF	IFF	0	
Fuel	Forward fuel boost	Fuel pressure low	0	
	Aft fuel boost	Fuel pressure low	0	
	Engine fuel pump	Fuel pump low	0	
	10% fuel	Fuel low level	0	
	Fuel filter	Fuel contamination	0	
Ordnance		Weapon jammed	0	
Hydraulic/pneumatic	Hydraulic pressure No. 1	No. 1 hydraulic low	0	
	Hydraulic pressure No. 2	No. 2 hydraulic low	0	

TABLE 22 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Instrument systems				
Fire detection system		Fuselage fire	0	
		Engine fire	0	
Oil temperature		Oil temperature high	0	
Chip detector	Chip detector	Trans chip	0	
		Engine chip	0	
Landing gear				
Auxiliary equipment				1
Power plant controls				
De-icing/anti-icing controls		Ice	0	
Throttle control system		Overspeed	0	
Oil temperature control system		Oil hot	0	
Engine air cooling control	Engine air	Engine air	0	
Power plant			0	
Propeller			0	
Power plants turbine				2
Transmission	Transmission oil bypass	Transmission filter clogged	0	
	Transmission oil pressure	Transmission oil pressure low	0	
	Transmission oil hot	Transmission oil hot	0	2
Chip detector	Chip detector	Transmission chip	0	
		Engine chip	0	3

TABLE 23

CH-47 Accident Statistics

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Airframe/fuselage				
Fuselage structure		Fuselage fire	0	
Wings/main rotor blade			7	24
Brakes	Parking brake on	Check caution panel	0	
Flight controls				24
Aileron				
Rudder and rudder trim		Controls not centered for taxi	1	
Helicopter cyclic control system		Controls not centered for taxi	15	
Helicopter collective control system		Controls not centered for taxi	4	
Helicopter tail rotor control system		Controls not centered for taxi		
Electrical/electronics				14
Power system (d-c)	Transformer rectifier failure	Transformer rectifier	7	
Power system (a-c)	Generator failure (a-c)	Generator failure (a-c)	1	
External power system	External power on (a-c)	External power on (a-c)		
	External power on (d-c)	External power on (d-c)		
Electronics system (radio/radar)			2	

TABLE 23 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Fuel	Fuel pressure drop	Fuel pressure low		8
	Fuel low caution light	Fuel low caution Fuel booster pump		
Ordnance				6
Hydraulic/pneumatic	Hydraulic system failure (left or right)	Hydraulic system failure (left or right) Utility hydraulic system		56
Instrument systems				43
Automatic pilot/stabilization	Stability augmentation No. 1 or No. 2 system	Stability augmentation No. 1 or No. 2 system		
Stall warning system (stick shaker)			1	
Fire detection system	Engine fire (No. 1 or No. 2 engine)	Engine fire (No. 1 or No. 2 engine)	4	
Rotor rpm dissipation indicator		Rotor speed abnormal	3	
Oil temperature			4	
Chip detector	Chip detector		2	
Master caution	Master caution	Check caution panel		
Landing gear	Wheels disphased	Over gross weight Check caution panel		9
Auxiliary equipment				3
Power plant controls				2
Oil	Low oil quantity	Low oil quantity	1	
Power plant				34

TABLE 23 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Propeller				5*
Power plant turbine	Engine fire	Engine fire		76
01 to 13			67	
Unknown, but suspect			9	
Helicopter transmission	Transmission oil pressure Transmission oil temperature	Transmission oil pressure Transmission oil temperature Overtorque		105
Chip detector indicator	Transmission chip detected Engine chip detected (left or right)	Transmission chip detected Engine chip detected (left or right)		9

*The reason for this entry is unknown; it is possible that it is caused by a keypunch error in the data.

TABLE 24

CH-54 Accident Statistics

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Airframe/fuselage				
Fuselage		Fuselage fire	0	
Tail cones	Tail skid up	Tail skid up	0	0
Brakes	Parking brakes on		0	0
Flight controls				
Cyclic control system			1	1
Electrical/electronics				
Power system (d-c)	No. 1 rectifier	No. 1 rectifier	0	
	No. 2 rectifier	No. 2 rectifier	0	
Power system (a-c)	No. 1 generator	No. 1 generator	0	
	No. 2 generator	No. 2 generator	0	
External power system	ENT power connected	Check caution panel	0	
APU power unit	AFP on			
	APP hydraulic pressure low	Check caution panel	0	
Electronics system (radar/radio)			0	0
Fuel	No. 1 fuel pressure	No. 1 fuel pressure low or fuel boost pump failure	0	
	No. 2 fuel pressure	No. 2 fuel pressure low or fuel boost pump failure	0	
	No. 1 engine fuel bypass	Fuel contamination or engine fuel control malfunction	0	

TABLE 24 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
	No. 2 engine fuel bypass	Fuel contamination or engine fuel control malfunction	0	
	Forward fuel low	Fuel low	0	
	Aft fuel low	Fuel low	0	
	Auxiliary fuel pressure	Check caution panel	0	2
Ordnance				1
Hydraulic/pneumatic	First stage servo	First stage servo		
	Second stage servo	Second stage servo		
	First stage tail rotor servo	First stage tail rotor servo		
	Utility hydraulic system failure	Utility hydraulic system failure		1
Instrument systems				
Automatic pilot/stabilization		Automatic flight control system	0	
Fire detection system	Engine fire	Engine fire		
		Fuselage fire	0	
Rotor rpm dissipation indicator		Rotor speed abnormal	0	
Chip detector	Chip detected	Chip detected	1	1
Landing gear	Landing gear kneeled	Check caution panel	0	
	Levelizer locked	Check caution panel		
Auxiliary equipment	Hoist oil pressure	Check caution panel	0	
	Hoist oil temperature	Check caution panel	0	
Power plant controls				

TABLE 24 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Oil				
Power plant				
Propeller/rotor	Rotor brake pressure	Rotor brake pressure	0	
Power plants turbine		Torque difference between engines Over gross weight warning Engine failure Free turbine N_2 flex cable failure		2
Helicopter transmission		Overtorquing Transmission oil pressure Transmission oil temperature Intermediate transmission oil pressure		1
Chip detector indicator		Chip detector	0	

TABLE 25

OV-1 Accident Statistics

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Airframe/fuselage				27
Fuselage structure		Fuselage fire	0	
Brakes			0	
Flight controls				
Elevator			1	
Rudder and rudder trim			1	
Wing flaps			1	4
Electrical/electronics				
Power system (d-c)	Instrument power failure	Instrument power failure	2	
		Inverter power failure		
Power system (a-c)	Electrical power supply	No. 1 generator failure		
		No. 2 generator failure	1	
Electronics system	IFF	Check caution panel	0	8
Fuel	Fuel strainer	Fuel contamination	0	
	Fuel level low	Fuel low	0	
	Fuel boost pumps	Fuel boost pumps	0	
	Fuel pressure No. 1 (No. 1 or No. 2)	Fuel pressure high (No. 1 or No. 2)	0	
	Fuel emergency caution light	Fuel metering control failure	0	
	No. 1 or No. 2 fuel-driven fuel pump	Engine-driven fuel pump failure	0	6
Ordnance				2

TABLE 25 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
Hydraulic/pneumatic		Hydraulic system failure		30
Instrument systems				
Automatic pilot stabilization		Automatic flight control system failure	0	
Stall warning system		Stall		
Fire detection system	Engine failure No. 1 or No. 2	Engine fire (No. 1 or No. 2) Fuselage fire	2	
Chip detector	No. 1 engine chip No. 2 engine chip	No. 1 engine chip No. 2 engine chip	10	
Landing gear	Wheels	Wheels not down		40
Auxiliary equipment	Left drop tank Right drop tank	Check caution panel	0	
Power plant controls				
De-icing/anti-icing controls	Engine ice	Check caution panel	0	
Throttle control system			1	
Propeller control system (feather reversing system)		Auto feather armed	2	
Oil		Oil pressure low (No. 1 or No. 2 engine)		1
Power plant				2
Propeller				32
Power plant turbine	Engine fire (No. 1 or No. 2) No. 1 engine chip detector No. 2 engine chip detector	Engine fire (No. 1 or No. 2) No. 1 engine chip detector No. 2 engine chip detector		

TABLE 25 (continued)

Aircraft Area	Current Warning	Potential Voice Warning	Incidents	Total
	No. 1 engine-driven fuel pump	No. 1 engine-driven fuel pump		
	No. 2 engine-driven fuel pump	No. 2 engine-driven fuel pump		
		No. 1 or No. 2 engine failure		121
Chip detector indicator			5	

VI. PILOT INFORMATION SURVEYS

A pilot information survey was conducted for each of the vehicles considered in this study. The survey, conducted in the form of a questionnaire, collected information related to general VWS design, pilot recommendations for the VWS priority sequence, the number and content of messages, and suggestions with regard to instruments that may not be needed in combination with a VWS.

1. Pilot Sample

The experience of the 180 pilots participating in the questionnaire survey is shown in Tables 26 and 27. It is shown that the pilots were highly experienced, averaging thousands of hours of flying time. The UH-1, CH-47, and OV-1 pilots were tested at the Army Aviation School, Fort Rucker, Alabama; the AH-1G pilots were tested at the Army Aviation School, Fort Hunter-Stewart, Georgia; and the CH-54 pilots were examined at Fort Rucker, Alabama and Fort Sill, Oklahoma. None of the pilots had any experience with a VWS.

2. Method

The questionnaire was administered to groups of pilots ranging in size from 1 to 50. Prior to administering the questionnaire, a full briefing on the purpose of the study, the questionnaire, and the VWS was given. The questionnaire administrator remained in the room with the pilots while the questionnaire was being completed so that he could answer any questions and collect the questionnaires prior to the departure of the pilots. The questionnaires took approximately 1-1/2 hours to complete. Generally, it appeared that the pilots were highly motivated.

3. Pilot Ranking

Four sections of the questionnaire were devoted to eliciting pilot recommendations for the VWS priority sequence. Two different methods for obtaining pilot rankings were used in combination with two different sets of failures, thereby resulting in four independent rankings. The results for each of the vehicles are shown in Tables 28 through 32 in Appendix C.

Previous experience in other questionnaire surveys and specific experience reported by Ref. 10, has shown that it is very difficult to obtain consistent ranking information. Therefore, it was desirable to obtain this information in a number of different ways to check results. Also, one of the techniques (paired comparison) is extremely time consuming, and the other (ranking) becomes less consistent as the length

TABLE 26

Summary of Experience for Pilots Used in Questionnaire Survey

Type of Experience	UH-1	AH-1G	CH-47	CH-54	OV-1
Length of service (years)	8.8(85)*	8.5(33)	15.2(20)	15.5(21)	15(15)
Total flying time (hours)	2449(87)	1851(33)	3205(21)	3421(22)	4412(16)
Total instrument time (hours)	146(74)	90(24)	100(19)	117(19)	206(16)
Flying time in combat zone (hours)	707(83)	733(33)	567(20)	421(21)	461(12)
Service in Viet Nam (months)	12(82)	12(33)	12.8(20)	11(22)	12(12)
Time since Viet Nam (months)	9(84)	8(33)	11(20)	26(22)	9(12)
Time at Aviation School (months)	13.5(88)	10(33)	15(21)	17(17)	42(15)
Experience with voice-warning systems	0	0	0	0	0
Number of pilots surveyed	88	33	21	22	16

*First number is average experience; number in parentheses is the number of pilots upon which the average is computed

TABLE 27

Experience of Pilots by Vehicle Type

Vehicle	Type of Vehicle for Which Pilots Provided Information				
	UH-1	AH-1G	CH-47	CH-54	OV-1
OH-13	376(74)*	217(20)	264.2(20)	384(21)	275(8)
CH-21	309(13)	155(2)	81(12)	461(11)	100(1)
OH-23	266(69)	149(29)	197(19)	281(19)	185(7)
CH-34	627(17)	535(6)	824(13)	886(13)	210(4)
UH-19	134(36)	112(25)	244(8)	147(15)	75(2)
CH-37	250(4)	961(1)	60(1)	861(9)	70(1)
H-25	26(4)	13(1)	26(6)	35(5)	--
YH-40	--	--	20(1)	2(1)	--
AH-1G	3(2)	81.5(33)	10(1)	--	--
UH-1	849(86)	916(33)	371(17)	618(22)	286(5)
CH-47	750(2)	--	765(20)	3(1)	--
CH-54	300(3)	--	--	162(22)	--
LOH	301(7)	3(1)	7(1)	--	--
O-1	625(33)	443(7)	266(8)	482(10)	766(16)
U-6	408(29)	142(7)	313(7)	352(10)	903(15)
U-1A	490(5)	30(1)	480(5)	550(5)	282(5)
U-8	124(8)	1400(1)	217(3)	253(4)	646(7)
LC-126	103(5)	200(1)	50(1)	59(3)	764(9)
OV-1	162(3)	50(1)	--	--	988(16)
U-9	--	--	--	4(1)	65(2)
CV-2	200(1)	248(2)	1100(2)	36(2)	200(2)
Other rotary	--	78(3)	3000(1)	--	800(1)
Other fixed wing	913(18)	--	--	1060(3)	200(1)

*First number is average experience; number in parenthesis is number of pilots upon which the average is computed

of the list to be ranked increases. To attempt to circumvent these difficulties, priority ranking was performed with a short and a long list of failures; the short list included only the most critical of present cockpit warnings, while the longer list included extra failures which require additional sensors, are new combinations of old warnings, or were less critical failures.

a. Paired-comparison technique

In the paired-comparison technique, each pilot was presented with all possible combinations of failures, two at a time. For each pair of failures, each pilot indicated which of the two failures he would wish to hear first if the two failures occurred at the same time. For the longer list with the CH-54, the pilots responded to 231 different comparisons. After the questionnaires were completed, a score was assigned to each failure which was the total number of times it was selected to be heard first over other failures. Subsequently, the failures were ranked by this score (as shown in Tables 28 through 32 in Appendix C).

b. Ranking technique

The ranking technique presented the pilots with a simple list of failures. The pilots placed a number next to each failure corresponding to its rank, starting at "1" and continuing until all failures had been numbered. To score the pilot response, a tally was made of the number of times a given failure had been selected in the No. 1 position, the No. 2 position, and so forth. The products of the tally count and rank were formed, summed, and averaged to obtain a mean-rank product. The mean ranks thus computed are shown in Tables 28 through 32 in Appendix C.

4. General Questionnaire

The pilots were also asked a number of general questions in yes-no or multiple-choice form. It was desired to collect some information relevant to general VWS design, the number of messages required to warn for multiple systems (multiple engines, multiple hydraulic systems, etc.), and specific information with regard to the content of messages. These results are shown in Table 33 (Appendix C). It will be noted that numerous questions were asked twice in different forms as a consistency check on the results obtained.

a. General VWS design questions

The results indicate that the pilots would like the option of disabling the VWS (1)*. Very few pilots object to using a woman's voice (2),

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*Numbers in parentheses indicate the relevant question number.

most think a man's voice would be obscured against a background of other messages (27), and the vast majority would prefer a female voice (31). The pilots would like a muting device incorporated (20) and would like the messages to go to all crew members (21). Even if the chip detector warning is a false alarm 9 times out of 10, they would still like the warning included (23). The pilots did not think the VWS would eliminate the visual annunciator panel (26), and thought the annunciator panel should duplicate the VWS (29). The pilots were divided on whether it would be sufficient for the VWS to simply announce to check the caution warning panel (25) and whether the VWS would reduce the visual burden of fault detection through instrument checks (28).

b. Number of messages required for multiple systems

Most pilots thought it necessary for the VWS to tell them which engine was on fire (3) or which engine had failed (10); moreover, they wanted to be told if both engines failed (8). Many said that it didn't matter which engine they were informed of first, but a number of OV-1 and CH-54 pilots indicated the left engine was more important (9).

The pilots clearly wanted to be told that both hydraulic systems were failing (6), and they did not want to be told of one system at a time (7). On the other hand, if only one hydraulic system was failing, the majority indicated it was not necessary to tell them which system it was (5); the CH-54 and CH-47 pilots, however, seemed to desire specific identification of the failed system.

c. Content of messages

The pilots quite emphatically do not want the voice warning to give the corrective action as well as the nature of the fault (24). It is desired to hear a single message for engine failure rather than a series of diagnostic messages such as EGT low, N_1 rpm low, etc. (11). For a number of messages, the pilots desire to hear that a parameter is either high, low, or abnormal, but in a number of instances their preference is not clearly indicated; the specific results are included in Table 33 (12 through 19) in Appendix C.

d. Consistency

At two places in the questionnaire, the pilots were asked whether a VWS message should be included for double-engine failure and for double-hydraulic failure. In the first case, they were asked if they wanted such a message (6, 8), and a strong response indicated that they did. In the second case, they were asked if such a message was needed (32, 33); again, the majority (averaged over all pilots) answered positively, but the bare majority of the CH-54 pilots answered negatively.

Thus, while the responses to these questions are not totally inconsistent, it is apparent that a variety of responses can be elicited by rephrasing a question and asking it again at a slightly later time.

5. Requirements for Simultaneous Presentation of Warnings

Following completion of the paired-comparison technique for ranking failures, the pilots were requested to go back over each comparison to consider if it might be necessary to hear of both failures at the same time rather than first one, then the other. The results are shown in Table 34 in Appendix C; this table only shows the comparisons where more than 25% of the pilots sampled on a given vehicle responded that they would want to hear about both failures at the same time. It may be seen that in most cases where the two failures were both very serious, or were related failures, there is a possible need for simultaneous presentation of the failures. This could be accomplished in the VWS by playing a combined message whenever two given failures occur simultaneously.

6. Mission-Dependent Emergencies

As part of the questionnaire the pilots were presented with a blank matrix, with failures listed down the left side and mission phases (takeoff, climbout, cruise, letdown, approach, and landing) listed across the top. The pilots were asked to check the mission phases in which they would respond differently to the emergencies; another column was provided to indicate that they would respond the same for all mission phases. The results for this portion of the questionnaire are tabulated in Table 34 in Appendix C; only those cases are shown where more than 25% of the pilots indicated a given emergency involved treatment which depended on the mission phase. Almost all of the entries in Table 35 in Appendix C involve takeoff, while a few involve landing, and only one case is shown where an emergency would be treated differently in cruise than in other mission segments.

7. Candidates for Instruments to be Eliminated by a VWS

The questionnaire also included a drawing of the instrument panel for the type of vehicle which each pilot was currently flying. The pilots were asked to indicate any instruments which might be eliminated when a VWS is added to the vehicle. All responses are shown in Table 35 in Appendix C; only a small percentage of the pilots polled indicated that any visual displays can be eliminated.

8. Recommendations for Words to be Used in VWS Messages

The questionnaire administered also included a section requesting the pilots to recommend descriptive words. The pilots were shown a list of emergencies for a given vehicle and requested to recommend a word, and the next most descriptive word, which best describes each fault. The results are discussed in Chapter VIII.

VII. COCKPIT INTEGRATION

A study of a VWS for installation in specific vehicles must not consider the VWS as isolated, for the VWS must be used in conjunction with other sources of information, other sense modalities, and in the environments unique to each vehicle. One question which arises is in regard to the possibility of removing some of the existing visual displays when a VWS is installed. The cockpits of Army vehicles are quite crowded, and, because some of these displays present information similar to that presented by the VWS, it is possible that some of these are completely redundant and could be removed. However, one must be sure that the VWS will always be effective in presenting the same information, and, in particular, one must be sure that the VWS will always be heard before removing another source providing the same information. Also related to these issues is the question: Is the visual caution panel necessary? Additionally, if the visual caution panel is necessary, what considerations should be made when incorporating the VWS?

In the following sections, analysis and discussion pertaining to these questions are presented. First, an analysis of the current visual displays is presented; then, the acoustic environment is discussed, along with a number of related considerations for improving the audibility and alerting value of the VWS. Finally, the considerations for integrating the VWS into the vehicles of concern to this study are summarized.

1. Analysis of Current Visual Displays

The VWS is only capable of presenting discrete qualitative information, whereas many of the visual displays are capable of presenting continuous quantitative information. Furthermore, while many visual instruments display information which overlaps with the information given by the VWS, in a great many cases the visual displays present other information or are useful for purposes other than initiating emergency responses.

To determine the possibility of removing some of the visual displays, an analysis was conducted (Tables 36 through 40). The visual caution panel was excluded from this analysis; however, all instrument panel displays are included. For each vehicle, the following steps were made:

(1) The use of the display was determined; if the use included primary flight operations (such as maintenance of altitude, attitude, etc.), no further consideration was given to removal of the visual display.

(2) It was determined whether the information presented was discrete and qualitative (regardless of the external appearance of the display) or continuous and quantitative; if only continuous quantitative information is presented, no further consideration was given to removal of the visual display.

(3) For the remaining displays, the importance, the amount of overlap with VWS information, and the possible display of information not presented by a VWS, were considered. This information is shown in Tables 36 through 40. Only where the overlap with the VWS is complete, with no further informational purposes, is a recommendation made that the visual display be considered for possible removal.

However, it may be seen that, based on the rules presented, the only visual displays to be considered for removal relate to the visual-warning system. Consequently, the question of removing visual displays relates to the question of the need for the visual-warning system and the associated caution panel.

2. Acoustic Environment

This subsection treats the acoustic environment of the vehicles concerned by this study and a number of considerations which relate to the ability (1) to hear the VWS against background noise and (2) to discriminate the VWS from other competing messages. The current study is basically analytical in nature; consequently, no empirical data were collected specifically for this purpose. All data presented in the following paragraphs were derived from the available literature.

a. Acoustic data

To determine the audibility of the VWS, the background noise must be well specified. The literature was examined for relevant data, which follow.

(1) UH-1B. The UH-1B aircraft tested by the USAHEL team (Ref. 6), recorded an overall noise level of 105 db during normal cruise conditions in the center-front portion of the vehicle. The range of these data (Table 41) was between 80 and 102 db over the entire frequency band.

(2) CH-47. The CH-47 aircraft tested (Ref. 6) recorded an overall noise level of 125 db in the cockpit area. The range of these data (Table 42) was between 97 and 124 db over the entire frequency band. Another study (Ref. 11), shows that

TABLE 41

Results of Noise Measurements Made on UH-1B/540* Aircraft

Octave Band Limits (Hz)	Center Frequency (Hz)	Acceptable Noise Levels (db)		Flight Condition			
				Normal Cruise		Hover	
		HEL Standard S-1-63B	Military Specification A-8806	Center Front	Center Rear	Center Front	Center Rear
22 to 44	31.5	--	--	102	106	100	94
44 to 87	63	119	111	99	103	99	102
87 to 175	125	114	111	99	98	97	97
175 to 350	250	107	110	94	97	96	94
350 to 700	500	99	104	93	94	90	94
700 to 1,400	1000	91	98	86	88	82	84
1,400 to 2,800	2000	89	92	82	83	77	79
2,800 to 5,600	4000	89	87	81	81	73	75
5,600 to 11,200	8000	91	87	80	80	71	72
Overall	--	--	113	105	109	104	105

*Measured noise data in db//0.0002 μbar; aircraft used was a standard UH-1B with the 540 door hinges rotor system

TABLE 42

Results of Noise* Measurements Made on the CH-47 Aircraft

		Acceptable Noise Levels (db)		Flight Condition			
				Normal Cruise			Hover
Octave Band Limits (HZ)	Center Frequency (Hz)	HEL Standard S-1-63B	Military Specification A-8806	Cockpit	Station 160	Station 240	Station 160
22 to 44	31.5	--	--	124	109	--	105
44 to 87	63	119	111	111	105	106	100
87 to 175	125	114	111	109	102	108	102
175 to 350	250	107	110	107	101	103	99
350 to 700	500	99	104	103	95	98	97
700 to 1,400	1000	91	98	104	99	100	101
1,400 to 2,800	2000	89	92	107	101	95	102
2,800 to 5,600	4000	89	87	108	96	95	98
5,600 to 11,200	8000	91	87	97	88	83	88
Overall	--	--	113	125	110	111	110

*Measured noise data in db//0.0002 μbar

at normal cruise the CH-47 test vehicle had an overall level of 111 db, with the range being 83 to 107 db in the cockpit. At higher power settings, this overall level increases to as high as 128 db.

(3) CH-54. The only measurements available on the CH-54 showed that, at cruise, a 119-db level was recorded in the left seat and 118 db in the back operator seat. This level decreased to 113 db in the left seat during hover operations. No frequency ranges or other measurements were available.

(4) OV-1 and AH-1G. Reference 6 showed that noise measurements were not taken in the OV-1 because of the danger of holding the measurement equipment in an operator's lap in case of emergency. To date, no measurements have been made in the AH-1G.

b. Alerting signals

Auditory stimuli, such as an alerting signal, possess attention-demanding qualities because they force themselves upon the recipient even though his attention may be riveted to some other task. Although the pilot may be flying in a heads-up mode, the introduction of a voice message will immediately capture his attention. However, there is a possibility that the voice message may be garbled or within the frequency range of the vehicle noise, and the pilot may not hear the entire message. An alerting signal, however, is more likely to attract the pilot's attention to the fact that a voice message will follow and, therefore, provide the time interval necessary for him to concentrate on the subsequent warning. Therefore, the probability that the pilot will hear the message correctly the first time is increased. A unique voice, such as a female's, may be sufficiently distinctive to alert the pilot, but in a very noisy environment the first words may be lost before attention is directed to the message.

MIL-STD-411C (Ref. 12) provides information on only an audio master warning signal. This document does not specify the use of an alerting signal prior to receipt of the voice message itself. Air Force Standard 803A-2 (Ref. 13) does, however, provide a specification: "The major concentration of energy in audio warning signals should be between 250 and 2500 [Hz], and the signal should be readily identifiable on the basis of components below 2000 [Hz]."

The sound pressure level recommended for the audio warning signal should "... be at least 10 decibels (db) above the maximum anticipated ambient noise level at the frequencies of the warning signal." This standard further states "... an alerting signal of 0.5 second should be

presented and the emergency or other condition requiring action should be specified in the first 2.0 seconds of the identifying or action signal." Woodhead (Ref. 14) specifies that the alerting signal should be referred to the level at the crew member's ear for the specific aircraft, "but should not significantly exceed 110 db, where 'startle' effects have been noted." These startle effects tend to produce a drop in efficiency. Burrows (Ref. 2) found that verbal signals generally evoked a quicker response than non-verbal, but, for a fast reaction, a non-verbal signal such as a fire bell was most effective. Referring again to MIL-STD-803A-2, it specifies that a verbal-warning device should consist of (1) an initial alerting signal (nonspeech), and (2) a brief standardized speech signal (verbal message). In another study (Ref. 4), it was found that a pure tone of 2500 Hz, presented intermittently through earphones with an aircraft noise in the background, was the most effective warning signal. They recommended the two-phase approach to this problem; i.e., presentation of a warning signal followed by the voice message. Other tones that might appear in the pilot's headset could be: the outer marker, a 400-Hz two-dashes-per-second tone, the middle marker tone of 1300 Hz (a dot-dash), and, if renewed, the inner marker tone proposed at 3000 Hz. Other tones could include the VOR signal, a series of fast Morse-coded tones, and the low rpm auditory warning, an oscillating buzzing tone. It does not appear that any of these signals will present a serious conflict with the recommended alerting tone of 2500 Hz.

c. Type of voice

MIL-STD-803A-1 (Ref. 15) specifies "the voice used in recording verbal warning signals should normally be male and mature." Figure 18 shows the frequency ranges for reproduction of both male and female speech. It indicates that male speech starts at a lower frequency (10^2) than the female range and also that it ends at a lower range. These data were obtained at a talking level of 70 db (considered by most to be average). The recommended range for alerting signals (Ref. 13) starts in the lower portion of female range and ends slightly higher than the center of this range. For the male range, it covers the center portion. The military standard recommendation is superimposed in Figure 18.

A female voice is possibly superior, because most pilots report they must monitor two to four radio frequencies simultaneously and a female voice providing the warning would be distinctive and easily heard over the other communications. USAHEL Letter Report 23 (Ref. 6) recommends the female voice "...should be retained for future message tape recording." Of course a voice in the low-frequency ranges where helicopter noise is highest, may not be heard as readily as a voice in the higher frequency ranges where helicopter noise tends to

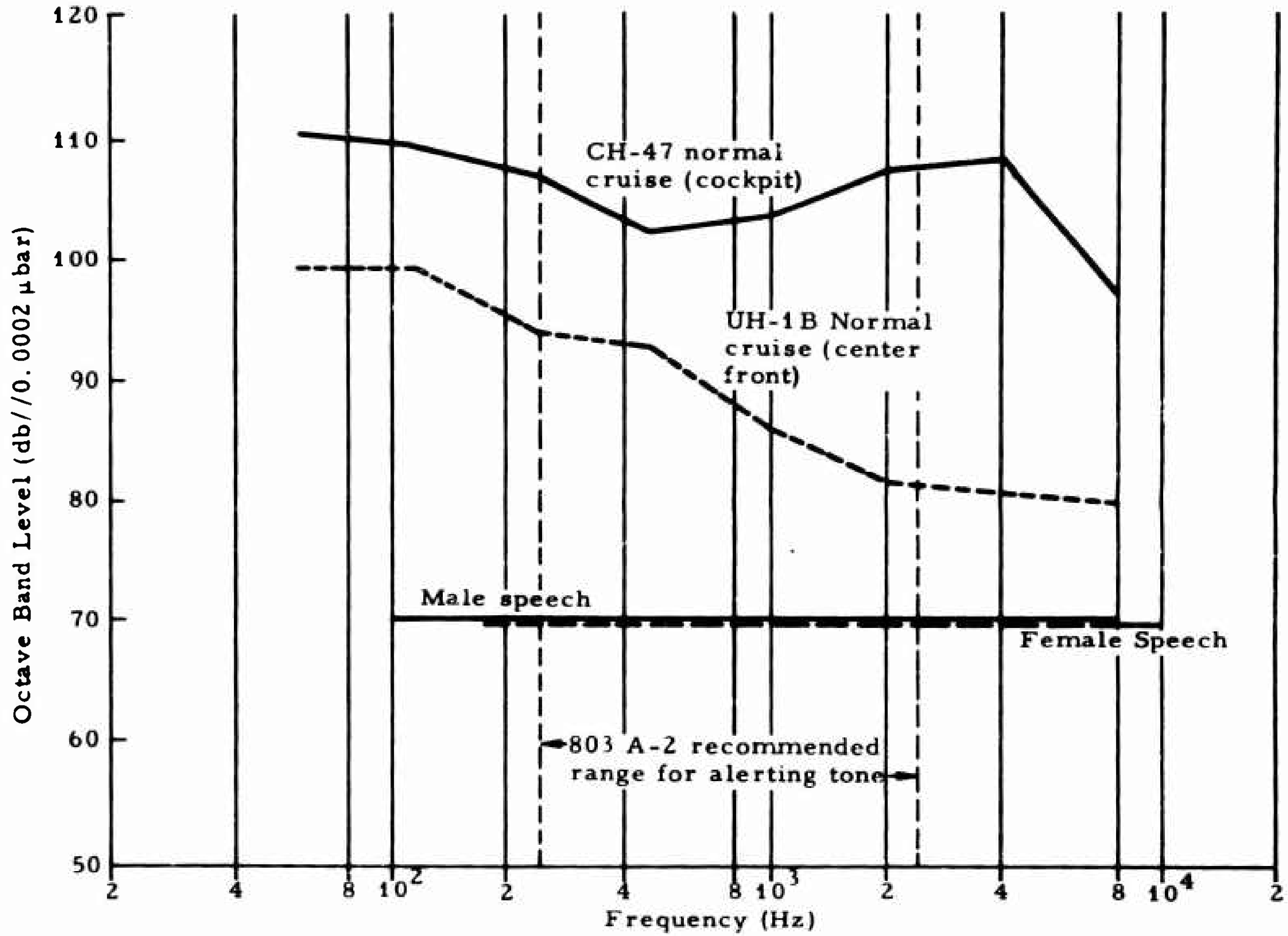

Figure 18. Speech and Noise Spectra

diminish. Thus, it is the frequency which is of concern and not the sex or age of the voice itself. The MIL-STD-803A-1 recommendation that the voice be male and "mature" provides the same vagueness as recommending that the voice used be female and "sexy." There will probably be greater acceptance by pilots of a female voice in the higher frequency ranges than a male voice in this same area. Reference 5 suggested the experimental use of a woman's voice, but, at that time, he did not feel it wise to incorporate it into "important operational systems." His reasoning was that a woman's voice tended to be slightly less intelligible than a man's and that, if frequently repeated, it would lose its uniqueness to command attention. Neither of these arguments was supported by research or references.

d. Headset and earplugs

The protective helmet APH-5 was made an item of U.S. Army aviation issue in 1959. It is, however, as reported in Ref. 6, a poor noise attenuator. A more detailed study (Ref. 16) showed that the APH-5 offers "high attenuation at test frequencies 3000 through 8000 Hz," but had "relatively low sound attenuation between 75 and 2000 Hz." The two recommendations that came out of this study were that either the earmuff be changed and, if this is not feasible, then replace the APH-5 "by a helmet with hign sound attenuation characteristics." Study data (extracted from Ref. 6) showed a range of noise attenuation by this helmet to be between -1 and 20 db. Within the frequency ranges of 250 and 2500 Hz (recommended range for alerting signals), attenuation is between -1 and 10 db. The 10-db level is effective at the higher frequency range, but helicopter noise is "loudest" at the lower ranges. At these lower ranges, the attenuation is considered (Ref. 16) to be "from poor to very poor."

The most commonly used earplug is the V51-R. Its range attenuation between the frequencies of 250 and 2500 Hz (recommended range for alerting signals) is between 17 and 36 db according to three different test installations (Ref. 6). The noise attenuation of the earplug is such that in the "noisiest" vehicle (CH-47) the sound pressure level output of the VWS could satisfactorily be increased to overcome the excessive ambient noise level, if there was a guarantee that all personnel wore the earplug on every flight. If earplugs are not worn, serious ear damage could occur. The present sound pressure level output of the VWS was measured at 110 to 117 db. Reference 5 states "A signal strong enough to over-ride a background noise of 115 or 120 db in the listener's ear is simply too strong to listen to under ordinary circumstances."

If, using an earplug, the voice-warning output could be increased to a 10-db level (or more) greater than the ambient noise level, there

should be little if any difficulty encountered by pilots in hearing the messages. The addition of a warning signal which would then conform to Ref. 13 might provide a system adequate for even the "noisiest" vehicle. However, an empirical study utilizing all of the components would be necessary to verify this fact.

e. Monitoring simultaneous messages

At various points during a mission, pilots may monitor as many as four voice channels simultaneously. In the past few years, much work has been done on the monitoring of simultaneous messages. Reference 17, for example, has utilized up to 15 simultaneous voice messages.

The techniques used by Rappaport were reported in Refs. 18 and 19 and many others. This technique is one in which the primary message; i.e., the one to be heard at this moment, is received in both ears, while the other messages that are to be continually monitored (air traffic control, etc.) are heard in only one ear. For the Army aviation pilot, this means that he could monitor his normal voice communications (which would be heard in one ear) and if the VWS is then activated this message would become the primary and be heard in both ears. The previous research shows that this primary message is perceived diotically in the center of the head, while the other messages are perceived as dichotic signals off to the side of the head. Under high ambient noise conditions, it has been found that the diotic signal is more intelligible than the others.

Another technique that may be used to aid hearing of the voice-warning message over other competing conversations is to mute the other conversations so that the VWS is sufficiently louder. If the other conversations in the pilot's headset can be considered part of the noise environment, then the difference between the VWS output and the total noise background (including other conversations) should be approximately 10 db (Ref. 13).

3. Integrating the VWS into Current Vehicle Cockpits

It may be seen from the vehicle noise data presented that these are very high noise environments which may make hearing the VWS difficult. Even higher noise levels may occur under special cases (such as weapon firing), and many other factors (such as high vibration) also may impair hearing. Only when the crew wears earplugs is it possible to improve the signal-to-noise ratio by increasing the VWS output; without the earplug, sufficient VWS output would result in ear damage to the crew. Consequently, one must conclude that unless sufficient steps are taken to improve VWS in such high noise environments (and data are collected to confirm sufficient audibility), the VWS may not always be heard.

If the VWS is not always heard, and properly understood, then it is difficult to recommend that any part of the visual-warning system be replaced by the VWS. Of course, it also is very likely that the visual system will not always be seen soon enough for efficient corrective action; hence, the probability of quick detection of an emergency is increased if both visual- and voice-warning systems are retained.

If the VWS audibility is increased by using an alerting signal, (or by using distinctive voices), it is possible that the probability of warning detection may be increased, but the pilot may be alerted without clearly hearing the message content. Under these conditions, the pilot will have to refer to the visual caution panel and other visual displays to clarify the nature of the emergency.

The best warning system therefore appears to be an integration of the visual- and voice-warning systems. Consequently, the design of the VWS should consider the nature of the existing visual-warning system and the other forms of information available. For example, the VWS effectiveness is reduced if any voice warnings are included which occur frequently and do not require immediate attention; consequently, the VWS may either not include such warnings or may alert the pilot to refer to the visual information available. Furthermore, if the voice- and visual-warning systems are to be used together, the design should attempt to integrate them into a composite system; for example, one should provide a single control which will reset both warning systems at the same time.

The high output that is required for the VWS to be heard over the normal noise background is a significant problem when the noise level is low. For example, if the engines fail, or are throttled down, then the VWS would be set to a level far too high; the effect would be to startle the pilot and perhaps seriously delay or degrade his response. The solution to this problem is to have the output level of the VWS depend on the noise level; however, if an automatic gain control which possesses some properties of hearing is required, then the additional complexity may be prohibitive. Another possibility is to have the VWS level dependent upon engine power, because the engine is the principal source of noise. In any event, the sound level control of the VWS and the high level required for acceptable signal-to-noise ratio are problems that must be solved for effective use of the VWS.

VIII. MESSAGE CONTENT

A number of analytic and empirical steps were taken to select a series of messages to announce each emergency that may occur. The characteristics of appropriate words which may lead to confusion with each other were studied. Then, two competing message styles were developed and subjected to test. These efforts are described in the following paragraphs.

In presenting the 180 pilots with the questionnaire, they first were asked to provide "one word" which, in their opinion, "best describes the condition" (fault) and then, in a second column, "the most descriptive" word (for the same fault). These lists were vehicle-oriented and thus provided words which pilots felt were important to the fault or failure described. A sample of the words selected by pilots in the order of selection is shown in the following tabulation.

Fault	First Choice	Second Choice
Low engine oil pressure	Oil, engine, pressure	Oil, pressure, engine
Right fuel boost pump off	Boost, fuel	Pump, fuel, boost
Fuselage fire	Fire, fuselage	Fuselage, danger
Fuel level low	Fuel, bingo, low	Low, bingo, level
Transmission oil pressure	Transmission, pressure	Pressure, oil

A composite list was then made of those words selected by three or more pilots, and this list was given to a group of engineering personnel who were asked to select words on the list which sounded similar to any others on the list.

The words selected conform to the findings of Traul and Black (Ref. 20), who found that words developed for discrimination tests were confusing because of similarity in beginnings or endings of the words. A sample of the words chosen to be confusing in the first of a series of discrimination tests is as follows:

hydraulic-cyclic	pressure-compressor	fuel-flow
regulator-generator	pedal-panel	metal-pedal
slow-low	fire-first	first-hoist
fire-rectifier	chips-check	
flow-slow-low	failed-kneeled	

Upon completion of this test, a breakdown of various words contemplated for the voice-warning system was made in terms of the word ending, sound, or beginning. The words fell into the categories shown in Table 43.

TABLE 43

Groups of Confused Words

-ion ending	transmission, caution, obstruction, malfunction	
-or, -ure, ier, er ending	rotor, detector, regulator, governor, generator, compressor pressure, temperature rectifier propeller, number, damper, power	
-o, -ol, -ow ending	low, flow, slow servo control	
-al, -el, -il, -le ending	metal pedal panel tail single, cable	
-st ending	first, hoist	
-op sound	drop, propeller	
-eel sound	wheels, kneeled	
-ic ending	hydraulic, cyclic, particle	
-ire sound	fire, rectifier	
other combinations	one, N_1 two, N_2 N_1, N_2 oil, tail tail, failed high, hydraulic SAS, bypass left, aft wing, single, landing kneeled, clogged	a-c, d-c external, electrical high, right gross, boost, both flex, left quantity, emergency dephased, d-c AFCS, a-c

A second revision based on these selections provided a more distinct set of words which, when matched with the fault condition and analyzed against previous research done on word discrimination, provided the initial messages for each vehicle.

1. Message Selection

Criteria for the selection of messages were established as follows:

(1) Two distinct sets of messages were to be established.

(2) Set No. 1 would conform to MIL-STD-411C (Ref. 12), which specifies that auditory messages would provide information on the following:

(a) The system; i.e., engine.

(b) The subsystem; i.e., one.

(c) The failure; i.e., fire.

(Consequently, a typical message in the arrangement would be "engine one fire.")

(3) Set No. 2 would be an attempt to provide each message with a different or "unique" first word.

(4) Pilot-oriented terminology would be used throughout.

Several problems developed because of these choices. If a set of messages was derived with the first word of each being different, maximum discrimination should occur because of the distinct qualities of each message; however, significant training would be necessary for the pilot to remember each message. The pilot could achieve this by activating the test button periodically and listening to the messages, by memorizing a list of the messages, or by encountering the various failures in the system. Once the first word of the message was learned, there should be a greater chance that the pilot would respond more quickly to the remaining words in the message; also, knowing the words that would follow the initial "learned" word would tend to make the message more discriminable. This key word would enable the pilot to better "hear" the remaining words. Several methods were utilized to determine the key word and the message content.

First, all possible failures for each vehicle were listed in their ranked order as an output of the questionnaires, the operational sequence, task analysis, etc. A review was made of the pilot-selected words and those

words most frequently selected were matched with the failure. Then, two sets of initial messages were developed according to the criteria previously established: (1) compliance with MIL-STD-411C, and (2) development of a key or unique first word for each message. The lists of messages which were developed for confusion testing appear in Tables 44 and 45.

After completion and after several critical reviews of the two sets of messages, it was established that the lists developed conformed to the established criteria and were, in fact, combinations of both methods— military standard and unique word. These lists were then tested on eight pilot-engineers who have worked extensively with pilots, with surveys, with air traffic control, and who have been actively involved in the development of systems for aircraft. These individuals were given the lists of messages in a force-choice array. They were asked to rank each message with every other message on a scale of 0 to 10, the more confused messages receiving the higher numbers. This was a modification of the Licklider (Ref. 5) technique. After scoring these lists, an average confusion factor was established. Tables 46 and 47 show the messages for both single- and multi-engine vehicles and the average confusion ranking associated with each message.

2. Index of Confusion Analysis

Within each of these lists there were some messages that definitely had a greater confusion with particular messages within the same list. These were termed "bad word combinations" and an example follows:

	Military Standard Format	
Multi-engine	Engine one failure	Engine one fire
	Engine one and two failure	Engine two failure
	Engine two chip	Engine one chip
	Engine two oil	Engine one oil
Single engine	Engine failure	Engine fire
	Engine rpm low	Engine rpm high
	Unique Word Format	
Multi-engine	Engine one failure	Engine two failure
	Fire engine one	Fire engine two
	Chips engine one	Chips engine two
Single engine	EGT high	EGT low
	Rotor rpm high	Rotor rpm low

TABLE 44

Message List—First Word Unique

Single Engine	Multi-Engine
Engine failure	Engine one failure Engine two failure Both engines
Fire, engine	Fire, engine one Fire, engine two Chip, engine one Chip, engine two Beep trim
Oil pressure	Oil quantity
Ice	Ice
N_1 low	N_1 low, engine one N_1 low, engine two
N_1 high	N_1 high, engine one N_1 high, engine two
EGT low	EGT one low EGT two low
EGT high	EGT one high EGT two high Torque difference
Rotor chip	--
Tail rotor	--
Fuselage fire	Fuselage fire
Electrical fire	Electrical fire Right-wing fire Left-wing fire Transformer
Generator	Generator
Inverter	Inverter
External power	External power connected
Transmission chip	Transmission chip
Low transmission pressure	Low transmission pressure
Hot transmission oil	Hot transmission oil Overtorque transmission

TABLE 44 (continued)

Single Engine	Multi-Engine
Hydraulic pressure	Hydraulic one pressure Hydraulic two pressure
Total hydraulic pressure	Total hydraulic pressure Intermediate transmission pressure Utility hydraulic system
SAS	AFCS (SAS) Cyclic trim Pedal damper Hover stick Flight controls not centered
Boost pump	Boost pump
Double boost	Double boost
Pump	Pump
Contaminated fuel	Contaminated fuel
Fuel control	Fuel control one Fuel control two
Low fuel quantity	Low fuel quantity
Rotor rpm low	Rotor rpm high
Rotor rpm high	Rotor rpm low Wheels Cargo hook Overweight Hoist oil pressure Temperature hoist oil Pressure rotor brake Rotor brake on APP on Hook unlocked Armed hook release Tail skid up Parking brake on Starter one on Starter two on Anti-ice on Pitot heat Tank, left-wing stuck Tank, right-wing stuck Propeller one Propeller two Stall Oxygen quantity low
Check caution panel	Check caution panel

TABLE 45

Message List—In Compliance With Military Specification

Single Engine	Multi-Engine
Engine failure	Engine one failure Engine two failure Engine one and two failure
Engine fire	Engine one fire Engine two fire
Engine chip	Engine one chip Engine two chip Engine beep trim
Engine oil quantity	Engine one oil pressure Engine two oil pressure
Engine ice	Engine ice
Engine rpm low	Engine one rpm low Engine two rpm low
Engine rpm high	Engine one rpm high Engine two rpm high
EGT high	EGT one high EGT two high
EGT low	EGT one low EGT two low Engine torque difference
Tail rotor chip	
Tail rotor	
Fuselage fire	Fuselage fire
Electrical fire	Electrical fire Right-wing fire Left-wing fire Transformer
Generator	Generator
Inverter	Inverter
External power connected	External power connected
Heater hot	Heater hot
Transmission chip	Transmission chip
Transmission oil pressure	Transmission oil pressure

TABLE 45 (continued)

Single Engine	Multi-Engine
Transmission oil temperature	Transmission oil temperature
	Transmission overtorque
Hydraulic pressure (one or two)	Hydraulic one pressure
	Hydraulic two pressure
	Hydraulic one and two pressure
	Intermediate transmission pressure
	Hydraulic utility system
SAS	AFCS (SAS for CH-47)
	Cyclic trim
	Pedal damper
	Hover stick
	Flight controls not centered
Fuel boost pump	Fuel boost pump
Fuel boost forward and aft	Fuel boost forward and aft
Engine fuel pump	Engine fuel pump
Fuel contaminated	Fuel contaminated
Fuel control	Fuel control one
	Fuel control two
Fuel quantity low	Fuel quantity low
Rotor rpm low	Rotor rpm low
Rotor rpm high	Rotor rpm high
	Wheels dephased, not down, not kneeled
	Cargo hook
	Over gross weight
	Hoist oil pressure
	Hoist oil temperature
	Rotor brake pressure
	Rotor brake one
	APP on
	Hook unlocked
	Armed hook release
	Fail skid up
	Parking brake on
	Engine one starter on
	Engine two starter on
	Engine anti-ice on
	Pitot heat

TABLE 45 (continued)

Single Engine	Multi-Engine
	Left-wing tank stuck
	Right-wing tank stuck
	Propeller one
	Propeller two
	Stall
	Oxygen quantity low
Check caution panel	Check caution panel

TABLE 46

Index of Confusion for Single Engine Messages

Unique First Word

Message	Average Ranking
Fire engine	0.785
N_1 high	0.776
EGT low	0.745
Rotor rpm high	0.696
Rotor rpm low	0.669
Low transmission pressure	0.650
Rotor chip	0.638
EGT high	0.625
Double hydraulic pressure	0.571
Hydraulic pressure	0.526
Chip engine	0.516
Fuselage fire	0.513
Tail rotor	0.508
Oil (pressure)	0.491
Transmission chip	0.433
Electrical fire	0.419
Hot transmission oil	0.401
Low fuel quantity	0.375
Fuel control	0.334
Generator	0.316
Inverter	0.303
N_1 low	0.272
Contaminated fuel	0.245
Double boost	0.191
Boost (pump)	0.187
External power (connected)	0.133
Check caution panel	0.089
Ice	0.080
Total	12.487
Average	0.445

Military Specification

Message	Average Ranking
Engine fuel pumps	1.241
Engine rpm high	1.080
Engine rpm low	0.785
Engine oil	0.589
Hydraulic one and two pressure	0.562
Fuel quantity low	0.535
Transmission oil temperature	0.464
Engine chip	0.401
Fuel boost forward and aft	0.339
Fuel contaminated	0.339
Engine fire	0.312
Tail rotor chip	0.267
Transmission oil pressure	0.089
SAS	0
Fuel boost (pump)	0
Total	7.003
Average	0.466

TABLE 47

Index of Confusion for Multi-Engine Messages

Unique First Word		Military Specification	
Message	Average Ranking	Message	Average Ranking
N_1 high engine two	1.400	Engine two rpm high	1.821
EGT two high	1.185	EGT two low	1.685
N_1 high engine one	1.150	Engine two rpm low	1.571
N_1 low engine two	0.914	EGT two high	1.557
Chips engine two	0.885	EGT one low	1.364
EGT two low	0.878	Engine one rpm high	1.350
Fire engine two	0.771	Engine two oil	1.242
EGT one high	0.735	EGT one high	1.150
N_1 low engine one	0.685	Engine one rpm low	1.071
Chips engine one	0.600	Engine one oil	0.971
EGT one low	0.500	Engine two chip	0.942
Fire engine one	0.407	Engine two fire	0.942
Left-wing fire	0.371	Right-wing fire	0.742
Engine two failure	0.300	Left-wing fire	0.707
Both engines	0.200	Engine one chip	0.678
Right-wing fire	0.128	Engine one fire	0.657
AFCS	0.107	Engine one and two failure	0.450
Intermediate transmission pressure	0.021	Fuel control two	0.392
Oil (quantity)	0.014	Engine two failure	0.250
Ice	0	Fuel control one	0.157
Total	11.251	Total	19.699
Average	0.562	Average	0.984

The reasons for bad word combinations are the same as for single word confusion—similar words occur in both sets, endings are the same, or beginnings have the same word or the same starting series of letters. A representative sample of "bad word combinations" in which the same sets of words occur is:

Engine two chip	Engine one chip
Rotor rpm high	Rotor rpm low
Fuel boost forward	Fuel boost

The words underlined in each set are the same and it is because of this that confusion occurs between sets. Another problem which developed was the fact that the pilot population showed no definite indication of standardized terminology in their selection of words. Rather, the words they chose covered a broad spectrum of words for each failure.

The similarity of words in a set is more prevalent in the military specification for development of voice messages because the message content is defined and must be developed using system, subsystem, and failure, in that order. For each set of faults associated with a particular system, there will be, by definition, at least the same first word. If there is more than one fault in a subsystem, there could be several messages with the same first and second word. To eliminate this problem and decrease the confusion of messages, it would be necessary to develop a unique set of words for each message (or at least a unique set of first words). This was the approach taken in opposition to the military specification. The results of this technique are evident in the total average confusion factor which follows:

	Unique First Word	Military Specification
Single engine	0.445	0.466
Multi-engine	0.562	0.984

In both cases, the unique word list has a lower average confusion than the military specification list; therefore, the test performed would tend to support this method as the better choice for these types of messages.

In some isolated cases, an individual word was used rather than a series of words, such as "ice" or "SAS," and the results of the confusion tests showed that these words were capable of standing alone. The score for confusion was 0, indicating that they were never confused with other words or series of words. Even though this is contrary to the findings of Miller (Ref. 21) that words are more intelligible when heard in context, there is every reason to believe that in these cases

the individual word not in context might be better understood and elicit the proper response without connecting it in a series.

A detailed study utilizing the VWS, headsets, helmets, earplugs, and ambient noise would have to be conducted to verify these results. The method of presentation also should be investigated, as well as the type and quality of the voice making the presentation.

3. Voice Quality

In two separate questions on the pilot opinion survey, the response was overwhelmingly in favor of a female voice. Only one report out of the many surveyed for this study (Ref. 5) questioned the use of the female voice at this time for major operational systems.

From the various other reports studied, analysis of personal communications, and studies of acoustic data, there is much evidence to support the use of the female voice in a VWS. The reason for this choice is not, however, because the voice is female, but because of the voice quality and the distinct characteristics of a female voice. Research may show that, as some suggest, the female voice is not as easy to understand as a male voice, but it is probably caused by the voice that was used when these results were obtained.

The selection of the voice to be used in a VWS should be done by conducting a detailed research study on voice quality, clarity, and ability to be understood by a large percentage of the male population under conditions that exist in the vehicles for which the system is to be used. The voice should be in the upper portion of female range and maintain a clear, well modulated, and even tone throughout the messages. By this means it would probably produce a quality which would exceed the normal frequency ranges of the various other headset inputs, such as the marker beacons, alerting tones, and the normal male voice communications. Only through an extensive research study in simulated or flight conditions will the appropriate voice be found.

4. Message Presentation

At the present time, the VWS has the capability of repeating a message for a total of 15 seconds and then repeating unless a higher priority message or a pilot over-ride takes place. The method of presentation could enhance the pilot's ability to hear certain messages and also could reduce the confusion factor associated with a particular message. In compliance with MIL-STD-803A-1, and A-2 (Refs. 13 and 15), the alerting tone would be presented for a period of 0.5 second and then followed immediately by the voice-warning message. When read slowly, the average voice message could be transmitted in approximately 3 seconds (for the longest message); thus, with a half-second pause between

each message, a repeat of three times would use only 10-1/2 seconds of the 15 seconds available. If a fourth repeat was added, it would still use only 14 seconds of the total time. If a higher priority message was triggered during the course of a message presentation, the alerting tone of this new message would cue the pilot, and the uniqueness of the first word should permit a more rapid response to the new warning. Thus, the pilot is forced to correct the fault condition or over-ride the VWS.

IX. DISCUSSION

A. RESOLUTION OF PRIORITY SEQUENCES

The purpose of this chapter is to attempt to resolve the differences between the various priority sequences made by the pilots and the study team. The resolution of these differences will lead to recommendations for the ranking of the emergency conditions.

The four rankings made by the pilots for each vehicle are shown in Chapter VI. A long and a short list were ranked by the paired-comparison technique and a long and a short list were ranked by assigning a rank to the emergency. Shortly after the pilot opinion data were collected, it was determined that several other emergencies or warnings might furnish the pilot with additional useful information. To incorporate this information within the pilot rankings and, in an effort to determine task-related factors, a paired-comparison ranking was made using a revised list of emergencies. The rankings obtained in this manner are shown in Chapter IV.

One of the reasons for resolving the rankings is the problem which occurs so frequently when dealing with subjective data related to a controversial problem: the pilot-ranked emergencies differ with each ranking technique and with the study-team rankings.

Where differences existed, the information and data which could aid in achieving resolution were applied to the problem. This information consisted of task analyses for the emergency conditions, operational sequence diagrams, mission analyses, responses to the general questionnaire, operator's manuals, and mission-dependent responses made by the pilots.

To achieve resolution of the ranking of items of approximately the same priority, the speed of response required and pilot judgments are two criteria that may be used. However, it should be noted that a number of other criteria (such as task requirements, consequences of non-response, and requirements for information to be presented in a particular order) establish the essential gross structure of the priority sequence and must not be violated by the application of secondary criteria.

As an initial step toward resolving the differences, the pilot rankings and the study-team rankings were evaluated for the points of agreement and disagreement. Examination of the pilot rankings for a given vehicle will show that a number of dissimilarities exist across the four different rankings; but, if the emergencies are grouped appropriately it will be seen that one group of faults is always first, another group is always second, etc. (except for a few specific emergencies). For

example, fuselage fire may always appear first where it is ranked, and then, while transmission pressure and engine failure do not always appear in the same order, these two faults always appear next in some order, and so on. The character of these data is interpreted to mean that specific groups can be ranked based on the pilot ranking data, but, within these groups, the pilot data are not sufficiently consistent to determine precise pilot recommendations. Consequently, within these groups other evidence must be used to determine the ranking of individual messages.

In the following sections, the emergencies are presented in groups based on both the pilot ranking data and results of ranking based on information requirements analysis. For these groups and the ranking of groups, there are no differences between the recommendations of the study team and experienced pilots. (Occasionally, some rankings were altered slightly to achieve agreement on the basis of groups, as is described in subsequent paragraphs.) Resolution is derived for each vehicle, and a discussion is presented with the final ranking derived. For each vehicle, refer to the illustrations showing the rankings performed by the study team (Chapter IV, Figures 13 through 17) and the pilots (Appendix C, Tables 28 through 32).

1. UH-1

The rankings for the UH-1 were grouped as follows:

(1) Group 1: fuselage fire, engine fire*, and engine failure.

(2) Group 2: transmission oil pressure, transmission oil temperature, transmission chips, tail rotor chips, engine oil pressure, EGT*, and N_1 rpm*.

(3) Group 3: rotor rpm and engine chips.

(4) Group 4: engine fuel pump.

(5) Group 5: hydraulic system.

(6) Group 6: fuel low, inverter, left fuel boost, right fuel boost, d-c generator, engine ice, fu filter bypass, and governor emergency position*.

(7) Group 7: auxiliary fuel, external power connected.

The finally resolved list is presented in Table 48.

*These emergencies were ranked by the study team, but not by the pilots.

TABLE 48

UH-1 Priority Sequence*

1. Fuselage fire
2. Engine fire
3. Engine failure
4. Transmission oil pressure
5. Engine oil pressure
6. Transmission oil temperature
7. Transmission chips
8. Tail rotor chips
9. EGT
10. Engine N_1 rpm
11. Rotor rpm abnormal
12. Engine chips
13. Engine fuel pump
14. Hydraulic system
15. Left fuel boost
16. Right fuel boost
17. Fuel low
18. Generator (d-c)
19. Inverter
20. Engine ice
21. Fuel filter bypass
22. Governor in emergency position
23. Auxiliary fuel low
24. External power connected

*The exact message content is shown in Chapter VIII (Table 44 or 45). Emergencies are described above in compact terms (e.g., engine failure, EGT); later, consideration is given to distinguishing between failures of a similar type (e.g., Engine No. 1 or Engine No. 2, EGT high or low or abnormal).

a. Group 1

For the first group, there appeared to be excellent agreement between all of the rankings. Engine fire was not ranked by the pilots; however, based on the task analysis of the UH-1 and the rankings of engine fire for the other vehicles in the study the study team assigned this emergency below fuselage fire.

b. Group 2

The second group of emergencies included a number of critical emergencies. Transmission oil pressure was ranked higher than the rest in the group. There was some disagreement with regard to the ranking for transmission oil temperature, transmission chips, tail rotor chips, and engine oil pressure. A principal controversy was whether engine oil pressure should be above or below transmission oil temperature, transmission chips, and tail rotor chips. Both emergencies are serious, because one emergency can result in engine stoppage while the other presents an indication of transmission problems. Further examination of the task analyses revealed no over-riding task differences. The problem was resolved by placing engine oil pressure above transmission oil temperature because, possibly the failure of the engine in the single-engine helicopter could be more serious than first considered. Transmission chips and tail rotor chips were ranked as one item by the study team because the response to both is the same.

The chip detector was consistently ranked below transmission oil temperature for all rankings. These two items were inserted into the list so that the ranking remained the same. The final two items in this group were items which were not ranked by the pilots but which were ranked by the study group. These items were inserted into the list below transmission/tail rotor chip.

c. Group 3

This group of emergencies had good agreement between all rankings. These items were inserted into the list as they are listed.

d. Group 4

There was some disagreement between the rankings for the next item on the list. The study group ranked auxiliary fuel tank emergency above engine fuel pump. However, upon further examination of the task analyses and the operators manuals, it was decided that auxiliary fuel low should be ranked very low in the list of emergencies. For this reason, this emergency was shifted to the last group of emergencies. Engine fuel pump was then inserted into the list.

e. Group 5

There was agreement for the importance of the hydraulic system failure. The rankings indicated that this item should be ranked hydraulic system No. 1 followed by hydraulic system No. 2.

f. Group 6

The next two groups of items included items which were considered to be relatively low on the list of priorities. In terms of discrimination between the items based upon the rankings, it appeared that the fuel boost rankings fall above the fuel low emergency. Taking all of the rankings into consideration for these two items, it would appear that the general trend seemed to indicate that this order of ranking should be followed. Examining the task analyses for the two emergencies indicated no response time differences; however, upon looking at the task requirement differences, the fuel boost pump could conceivably affect engine performance more immediately than fuel low. The ranking was resolved by placing fuel boost pump above the fuel low emergency. The next two items placed upon the list were the generator emergency followed by the inverter emergency. The rankings did not agree unanimously. However, examination of the task analyses indicated that there were no response time differences nor were the task requirements different. Using the general trend as a basis, the ranking was resolved. The three items which were assigned the lowest rankings in this group were engine ice, fuel filter bypass, and governor in emergency position.

g. Group 7

The last group was transferred to the list to complete the list of emergencies for the UH-1. The task analyses and the rankings indicated that the list should be ranked as shown.

2. AH-1G

The rankings of the AH-1G were grouped as follows:

(1) Group 1: fuselage fire* and engine fire.

(2) Group 2: engine failure.

(3) Group 3: transmission oil pressure, rotor rpm, engine oil pressure, engine rpm*, chips (transmission and engine), transmission oil temperature, EGT, and engine fuel pump.

(4) Group 4: engine oil bypass and transmission oil bypass.

*These emergencies were ranked by the study team, but not by the pilots.

(5) Group 5: fuel low, forward fuel boost, aft fuel boost, engine air, hydraulic pressure No. 2, hydraulic pressure No. 1, and fuel filter.

(6) Group 6: inverter and generator.

(7) Group 7: SAS, governor in emergency position, IFF, and external power.

The final rankings are shown in Table 49.

a. Group 1

In terms of grouping, the AH-1G is similar to the groups established for the UH-1. The first two items in the list of emergencies for the AH-1G are fuselage fire and engine fire. Neither of these two items was ranked by the pilots, but there is good evidence, based upon the task analysis for the AH-1G and the rankings for other aircraft, that these items would be placed at the top of the priority list.

b. Group 2

The next item in the list was engine failure. There was good agreement across all of the lists for this item.

c. Group 3

The third group included many of the most serious emergencies for the Cobra. Looking across all rankings for the emergencies, it seems that the next item on the list should be transmission oil pressure. There is not complete agreement upon the placement of engine oil pressure, transmission oil temperature, and rotor rpm. Looking at the task analyses it would appear that the shortest response time is for the rotor rpm emergency. The response times for engine oil pressure and transmission oil temperature are the same. Based upon the response time, it was decided that rotor rpm would be placed above engine oil pressure and transmission oil temperature. There appeared to be no over-riding task differences between engine oil pressure and transmission oil temperature. However, most of the rankings indicated that engine oil pressure should be placed above transmission oil temperature and, therefore, the emergencies were inserted into the list in this order. Again, it seemed to indicate that engine failure for single-engine helicopters is much more important than it was initially considered. The next item placed upon the list was EGT abnormal. There was good agreement on the lists in which it was ranked. Engine N_1 rpm was the next item placed upon the list. This item was not ranked by the pilots; however, it was ranked to fall below EGT by the study team. Engine fuel pump was the next item placed on the list. Although there was slight differences among all the rankings, it did appear that this item was generally ranked above chip detector in the priorities. The next two items placed upon the list were transmission chip and engine chip.

TABLE 49

AH-1G Priority Sequence*

1. Fuselage fire
2. Engine fire
3. Engine failure
4. Transmission oil pressure
5. Rotor rpm
6. Engine oil pressure
7. Transmission oil temperature
8. EGT abnormal
9. Engine N_1 rpm low
10. Engine fuel pump
11. Transmission chips
12. Engine chips
13. Engine oil bypass
14. Transmission oil bypass
15. Hydraulic pressure No. 2
16. Hydraulic pressure No. 1
17. Forward fuel boost
18. Aft fuel boost
19. Fuel low
20. Engine air
21. Fuel filter
22. Generator
23. Inverter
24. SAS
25. Governor in emergency position
26. IFF
27. External power connected

*The exact message content is shown in Chapter VIII (Table 44 or 45). Emergencies are described above in compact terms (e.g., engine failure, EGT); later, consideration is given to distinguishing between failures of a similar type (e.g., Engine No. 1 or Engine No. 2, EGT high or low or abnormal).

d. Group 4

There was some disagreement in the ranking of the next two items. Part of the rankings seem to indicate that engine oil bypass should be placed before transmission oil bypass. However, another set of rankings indicate that ranking should be reversed. Examination of the task analyses and the operator's manuals indicated that there was no difference in response time or in the task requirements. Again, consideration of the rankings indicated that the parameter relating to the engine would probably be considered to be more important in terms of consequences. Therefore, the engine oil bypass was ranked above the transmission oil bypass.

e. Group 5

This group of emergencies included items which were often difficult to discriminate between in terms of their relative importance. Examining the lists of rankings, it appears that hydraulic pressure No. 2 and hydraulic pressure No. 1 should be ranked next on the list. These items appear above fuel boost in some of the rankings and below in others. Examination of the task analyses and the operator's manual for this emergency indicated that there were no critical differences in response times or response requirements which would resolve the ranking. However, most of the rankings seemed to indicate that hydraulic pressure No. 2 and hydraulic pressure No. 1 should be placed above fuel boost and, therefore, the items were placed upon the list in this order. Forward fuel boost, aft fuel boost, and fuel low were the next items added to the list. Again, the rankings varied among the lists, indicating that the differences in preferences were small. The task analyses indicated that fuel low required the fastest response time. However, upon reconsidering the importance of the fuel boost system to the continued operation of the aircraft engine and the potential consequences of a fuel boost failure at an altitude where it could cause fuel starvation, it was thought that these items should be placed on the list as indicated. Engine air and fuel filter were the next items placed upon the list. There was good agreement for all lists on the order of their appearance.

f. Group 6

This group was transferred to the list in the order of appearance. The different rankings disagreed about the exact position of these items; however, the task analyses indicated no response time differences and no task requirement differences that would indicate the requirement for a different ranking.

g. Group 7

The final items placed on the list were SAS, governor in emergency position, IFF, and external power connected. These items were transferred to the final list in this order. About the only item for which

there was disagreement was the governor in emergency position. This warning is currently a light on the fault warning panel which tells the pilot that the automatic governor has been manually locked out. Based upon the task analyses for the AH-1G, it was thought that this warning should be at the bottom of the priority list.

3. CH-47

The rankings for the CH-47 were grouped as follows:

(1) Group 1: both hydraulic systems.

(2) Group 2: fuselage fire and engine fire.

(3) Group 3: transmission oil pressure, transmission oil temperature, transmission chips, engine failure, and hydraulic systems.

(4) Group 4: engine chips.

(5) Group 5: EGT No. 1 engine*, EGT No. 2 engine*, N_1 rpm No. 1 engine*, N_1 rpm No. 2 engine*, overtorque, rotor speed abnormal, and fuel pressure.

(6) Group 6: SAS, fuel low, fuel booster pump, over gross weight, a-c generator, transformer rectifier, difference in torque*, and utility hydraulic system.

(7) Group 7: wheels dephased, parking brake on, heater hot, external power on (a-c), external power on (d-c), cargo hook open, and controls not centered.

The finally resolved ranking is shown in Table 50.

a. Group 1

The first item to be placed on the list for the CH-47 was the failure of both hydraulic systems. This item was not ranked by the study team because it was thought that a warning would not be required since the failure of both systems is normally the first in a fatal sequence of events.

b. Group 2

This group consisted of fuselage fire and engine fire. The exact arrangement of these two emergencies was different for several of the rankings. The task analyses indicated no response time differences or response requirement differences. About the only information that could

*These emergencies were ranked by the study team, but not by the pilots.

TABLE 50

CH-47 Priority Sequence *

1. Both hydraulic systems
2. Fuselage fire
3. Engine fire
4. Engine failure
5. Transmission oil pressure
6. Transmission chips
7. Transmission oil temperature
8. Hydraulic system failure
9. Engine chips
10. EGT No. 1 engine
11. EGT No 2 engine
12. N_1 rpm No. 1 engine
13. N_1 rpm No. 2 engine
14. Rotor speed
15. Overtorque
16. Engine oil low
17. Fuel pressure
18. Utility hydraulic pressure
19. Fuel boost pump
20. Fuel low
21. Torque difference
22. Generator failure (a-c)
23. Transformer rectifier failure
24. SAS
25. Over gross weight
26. Controls not centered for taxi
27. Wheels dephased
28. Parking brake on
29. Heater hot
30. External power on (a-c)
31. External power on (d-c)
32. Cargo hook open

*The exact message content is shown in Chapter VIII (Table 44 or 45). Emergencies are described above in compact terms (e.g., engine failure, EGT); later, consideration is given to distinguishing between failures of a similar type (e.g., Engine No. 1 or Engine No. 2, EGT high or low or abnormal).

be applied to the ranking of these two items was the fact that for other vehicles the rankings indicated that fuselage fire should be placed above engine fire. These data were used to resolve the ranking.

c. Group 3

The next group of items was difficult to rank. There was little agreement between any of the rankings other than the items consistently being ranked close together. The task analyses indicated that engine failure required the fastest response time. The response times for the other items in the list were the same. Therefore, engine failure was placed on the list as the next item. There was good agreement for all rankings that transmission oil pressure should be the next item on the list, so it was transferred. The ranking for transmission oil temperature, transmission chips, and hydraulic systems was not easily determined. The task analyses indicated that there were no differences in response times or in task difficulty that might aid the resolution of the ranking. The majority of rankings indicated that hydraulic system should be placed above transmission oil temperature. In the absence of other information, this was the next item placed on the list. Using the pilot and study team rankings as a tool for resolving the priority sequence, the data indicated that transmission chips should be ranked above transmission oil temperature. These items were transferred to the list in this order.

d. Group 4

This group consisted of engine chips. There appeared to be good consistency among the rankings for this item, so it was transferred to the final list.

e. Group 5

The next group included four items which had not been ranked by the pilots, but which had been given a priority sequence by the study team. Based upon the ranking of the study team, EGT No. 1 engine, EGT No. 2 engine, N_1 rpm No. 1 engine, and N_1 rpm No. 2 engine were transferred to the list of resolved rankings. There was relatively good agreement on the rankings for the placement of low oil over fuel pressure. There was disagreement over the placement of overtorque, rotor rpm, and fuel pressure low. The task analyses for these items indicated that overtorque and rotor speed have faster response time requirements than oil low and fuel pressure low, and, therefore, should be ranked higher. There were no task differences between rotor speed and overtorque; therefore, it was decided that the issue would have to be resolved by re-examining the rankings. Rotor speed was placed above overtorque on two of the three lists that were made. Using this information, rotor speed, overtorque, oil low, and fuel pressure low were transferred to the final list.

f. Group 6

The first item to be considered in this group was the utility hydraulic system. There was relatively good agreement among the rankings for the placement of this item. The listing for the remaining items was not clearly defined, and the relative position of these items differs. Referring to the task analyses for the emergencies indicates that the response times for fuel booster pump, fuel low, over gross weight, and torque difference are faster than the response times for a-c generator, transformer rectifier failure, and SAS. The task differences indicated that fuel boost pump can affect engine performance at higher altitudes; it is suspected that fuel boost pump emergencies may require slightly shorter response times than fuel low. Difference in engine torque does not have the consequences on flight that are implied by the fuel low situation. Difference in engine torque was not ranked by the pilots; however, ranking by the study team indicated that it should be placed below either fuel low or fuel boost pump. The ranking for over gross weight was puzzling. Although the response time for this emergency appeared to be shorter than that required for the SAS, it was ranked below SAS on two of three rankings. Reconsideration of the task response times indicated that the response time for over gross weight may have been somewhat overestimated. The ranking of this item was placed below the SAS emergency. There was disagreement over the placement of a-c generator failures and transformer rec[illegible]r failures. Both of these items were ranked higher than SAS emergencies. The task analyses indicated no major differences. The majority of rankings indicated that a-c generator should be placed higher in the list. Based on the analysis, utility hydraulic system, fuel boost pump, fuel low, torque difference, a-c generator failure, transformer rectifier failure, SAS, and over gross weight were transferred to the list in this order.

g. Group 7

The last group of items was obtained from the long list of pilot rankings. Only one item from the list, controls not centered, was ranked by both pilots and the study group. In all rankings it was at the bottom of the list. However, many of the items were not ranked by the study group because they were considered to be low on the priority list; therefore, they would never receive a position on the VWS, because of its limitation of 20 messages. Controls not centered is a warning which would be given to the pilot who was preparing to taxi the CH-47 before centering his controls. In this aircraft, failure to center the controls prior to taxi can result in knocking out droop stops and even fuselage damage. In terms of response times, it requires a shorter response time than any of the other items in this group. Based on response time, this item was transferred to the resolved list. Wheels dephased, parking brake on, heater hot, external power on (a-c), external power on (d-c), and cargo hook open were transferred to the list in this order because there was good agreement between the ranking they received and the task analysis.

4. CH-54

The rankings for the CH-54 were grouped as follows:

(1) Group 1: fuselage fire.

(2) Group 2: engine fire and transmission oil pressure.

(3) Group 3: transmission oil temperature, intermediate transmission oil pressure, No. 1 engine failure*, and No. 2 engine failure*.

(4) Group 4: hydraulic system, engine fuel control malfunction, N_2 flex cable failure, chip detector, EGT No. 1 engine*, EGT No. 2 engine*, N_1 rpm No. 1 engine*, N_1 rpm No. 2 engine*, overtorque, and engine oil pressure*.

(5) Group 5: first stage tail rotor servo, fuel contamination, rotor speed abnormal, and fuel boost pump.

(6) Group 6: utility hydraulic pressure low, fuel low, electrical power failure, d-c electrical system, AFCS, over gross weight, and torque difference between engines.

(7) Group 7: parking brake on, rotor brake pressure, hoist oil pressure, engine starter on, heater hot, landing gear kneeled, hoist oil temperature, levelizer locked, APP on, engine anti-ice, external power connected, turn and slip, pitot heat, and IFF.

The final ranking is shown in Table 51. The ranking for the CH-54 was perhaps the most difficult to accomplish of the five rankings. There was an unusually large number of emergencies to rank because of the complexity of the vehicle.

a. Group 1

The first item on the list was fuselage fire. There was good agreement between all lists for this item.

b. Group 2

The next items placed on the list were engine fire and transmission oil pressure. There was little agreement between the rankings for these items. Three of the four rankings made by the pilots indicated that transmission oil pressure should be placed above engine fire. However, one of the pilot rankings and the ranking made by the study group indicated

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*These emergencies were ranked by the study team, but not by the pilots.

TABLE 51

CH-54 Priority Sequence*

1. Fuselage fire
2. Engine fire
3. Transmission oil pressure
4. Transmission oil temperature
5. Intermediate transmission oil pressure
6. No. 1 engine failure
7. No. 2 engine failure
8. Hydraulic failure
9. Overtorque
10. N_2 flex cable failure
11. Engine fuel control malfunction
12. Chip detector
13. EGT No. 1 engine
14. EGT No. 2 engine
15. N_1 rpm No. 1 engine
16. N_1 rpm No. 2 engine
17. Engine oil pressure
18. First stage tail rotor servo
19. Rotor speed abnormal
20. Fuel contamination
21. Fuel boost pump
22. Torque differences between engines
23. Over gross weight
24. Fuel low
25. Utility hydraulic pressure
26. Electrical power failure (a-c)
27. Electrical system (d-c)
28. AFCS
29. Parking brake on
30. Rotor brake pressure
31. Hoist oil pressure
32. Engine starter on
33. Heater hot
34. Landing gear kneeled
35. Hoist oil temperature
36. Levelizer locked
37. APP on
38. Engine anti-ice
39. External power connected
40. Turn and slip
41. Pitot heat
42. IFF

*The exact message content is shown in Chapter VIII (Table 44 or 45). Emergencies are described above in compact terms (e.g., engine failure, EGT); later, consideration is given to distinguishing between failures of a similar type (e.g., Engine No. 1 or Engine No. 2, EGT high or low or abnormal).

that engine fire should have the higher priority. Examination of the task analyses for these two failures indicated that the response times are shortest for the engine fire. This consideration resolved the ranking so that engine fire was placed above transmission oil pressure.

c. Group 3

The next group of items was not entirely consistent in the rankings. Transmission oil temperature sometimes was ranked above intermediate transmission oil pressure and sometimes below. The task analyses for these two items did not indicate a difference in response times or in task difficulty. Thus, resolving the issue based on task information was not possible. As a general trend, the rankings seemed to indicate that transmission oil temperature should be ranked above intermediate transmission oil pressure. The two items were transferred to the resolved list, based on this trend. The final items in the group were not ranked by the pilots. However, the study group ranked these items below intermediate transmission oil pressure.

d. Group 4

In this group, there was good agreement for the hydraulic system failure. In most rankings, it was above engine fuel control. Based on the rankings, the exact arrangement of the engine fuel control malfunction, N_2 flex cable failure, and overtorque emergencies was not clear. Examination of the task analyses indicated that the overtorque and N_2 flex cable failures require a faster response than the engine fuel control malfunction. However, the task differences between the N_2 flex cable failure and overtorque do not indicate the requirement to rank one above the other. In terms of potential consequences, the overtorque emergency is probably the most serious because transmission failure could occur. However, the N_2 flex cable failure is often difficult to diagnose. The potential consequences of the overtorque emergency warranted ranking this item next on the list. The next items placed on the list were N_2 flex cable and engine fuel control malfunction, followed by the chip detector. On most rankings, the chip detector was ranked in this group. However, in one of the rankings (the long numerical ranking by the pilots) the chip detector was ranked quite low. This low ranking was treated as an artifact of this particular ranking technique. The next four items placed on the list were not ranked by the pilots. According to the study-team rankings, however, the warnings for EGT No. 1 engine, EGT No. 2 engine, N_1 rpm No. 1 engine, N_1 rpm No. 2 engine, and engine oil pressure would be placed on the list at this point.

e. Group 5

There was some disagreement about the arrangement of the items in this group. The task analyses indicated that the response time for the first stage tail rotor servo and rotor speed abnormal were shorter than

the response times required for fuel contamination or fuel boost pump failure. There were no over-riding task differences between the first stage tail rotor servo or rotor speed abnormal that would aid in resolution of the ranking. The consequences of both emergencies seem to be equally severe. To resolve the priorities, all rankings were compared for general trend. It appears that the first stage tail rotor servo should be ranked above rotor speed abnormal. These items were inserted into the list in this order. There is good agreement among all lists for placing fuel contamination above fuel boost pump. These items were inserted into the list in this order.

f. Group 6

There were some inconsistencies in the rankings for the next group of items. Examination of the task analyses for the emergencies indicated that the response times for fuel low, torque difference between engines, and over gross weight were shorter than other items within the group. The rankings for these three items did not help to resolve the priorities, nor did the task requirements indicate which items should be placed above or below. The items were so closely ranked that a pattern did not appear in the rankings. This problem was resolved by examining the task for the emergencies. Fuel low response time was considered to be somewhat slower than the response time for torque differences between engines or over gross weight. The latter two response times were probably very close. However, over gross weight would probably be critical only during the landing and takeoff phases of flight. Torque differences between engines were considered to be critical during all phases of flight. These items were added to the list in this order. The next item added was utility hydraulic system. There was relatively good agreement on all rankings for this item. The final items placed on the resolved list were electrical power failure (a-c), electrical system (d-c), and AFCS. There was relatively good agreement on all rankings for this ordering, and the task differences did not indicate to the contrary.

g. Group 7

The items in this group were not ranked by the study group because they were considered to be relatively low in priority. These items were added to the final ranking in the order ranked by the pilots. Generally, these rankings agreed with th task response times and task requirements.

5. OV-1

The rankings for the OV-1 were grouped as follows:

(1) Group 1: wheels.

(2) Group 2: fuselage fire, wing fire, engine fire, double engine failure, single engine failure, and electrical fire.

(3) Group 3: EGT*, engine fuel pump, N_1 rpm*, oil pressure, fuel pressure, and hydraulic system.

(4) Group 4: engine chips and fuel low.

(5) Group 5: stall, fuel boost, fuel strainer, inverter, and electrical power.

(6) Group 6: fuel emergency, drop tank, AFCS, and IFF.

The final ranking is shown in Table 52.

a. Group 1

The wheels emergency was elevated to top priority in the list even though it was ranked somewhat lower in all rankings. This was done because the wheels warning is mission-dependent since it is important only during landing. During landing, pilots strongly indicated that the wheels warning would probably take precedence over all other emergencies, including fire. With an appropriate sensor arrangement, the wheels warning will not appear (and, therefore, did not affect the ranking) except during approach and landing.

b. Group 2

In the second group, all lists indicated that fuselage fire would be rated at the top, followed by wing fire, engine fire, double-engine failure, and single-engine failure. Electrical fire was ranked on one list and appeared to fall below single-engine failure.

c. Group 3

In this group, the warnings for N_1 rpm and EGT were ranked by the study team, but not by the pilots. There appeared to be good agreement between the two sets of rankings; therefore, it seemed reasonable to insert the EGT warnings for the left and right engine above the fuel pump warnings. The N_1 rpm warnings for the left and right emergencies were inserted after the engine fuel pump warnings.

There was some disagreement over the placement of the warning for fuel emergency (No. 1 or No. 2). The pilots ranked this warning toward the bottom of the list although the study team ranked the emergency below N_1 rpm. Upon examining the task analyses, it was thought that the pilots were considering that the warning light shown on the annunciator panel actually will not appear until the pilot places the fuel control for an engine in the emergency position. However, the study team considered the emergency as the failure of the automatic fuel metering control which forces the pilot to place the engine fuel switch in the emergency

*These emergencies were ranked by the study team, but not by the pilots.

TABLE 52

OV-1 Priority Sequence*

1. Wheels
2. Fuselage fire
3. Wing fire (left or right)
4. Engine fire (No. 1 or No. 2)
5. Double engine failure
6. Single engine failure (No. 1 or No. 2)
7. Electrical fire
8. EGT left engine
9. EGT right engine
10. Engine fuel pump (No. 1 or No. 2)
11. N_1 rpm left engine
12. N_1 rpm right engine
13. Engine fuel metering control (No. 1 or No. 2)
14. Engine oil pressure (No. 1 or No. 2)
15. Fuel pressure
16. Hydraulic system
17. Engine chips (No. 1 or No. 2)
18. Fuel low
19. Fuel boost
20. Fuel strainer
21. Inverter
22. Electrical power
23. Fuel emergency (No. 1 or No. 2)
24. Stall warning
25. Drop tank (left or right)
26. AFCS
27. IFF

*The exact message content is shown in Chapter VIII (Table 44 or 45). Emergencies are described above in compact terms (e.g., engine failure, EGT); later, consideration is given to distinguishing between failures of a similar type (e.g., Engine No. 1 or Engine No. 2, EGT high or low or abnormal).

position. After looking at the engine fuel control emergency shown in the task analyses, it is apparent that this emergency can be serious because engine stoppage can occur; hence, the study team ranking was allowed to stand and the title of the emergency was changed to engine fuel metering control for clarification.

There was good agreement between the lists for the ranking of oil pressure, fuel pressure, and the hydraulic system failure. These items were inserted into the list as a group, in this order. Because the hydraulic system does control the operation of the wheels and flaps (an operation which is somewhat mission-dependent), some consideration was given toward trying to elevate this emergency in the same manner as the wheels warning. However, the operation of the flaps for slow flight purposes and use during other phases of flight negated this approach to the problem.

d. Group 4

In this group, the ranking of the study team inserted the stall emergency between the two items within this category. However, the rankings of the pilots indicated that the emergency probably should fall below the fuel emergency warning. Examining the task analyses seemed to indicate that the stall warning requires a very fast response in comparison to the other emergencies. It is surmised that the pilots ranked the emergency based on their operational experience with the OV-1. Discussions of the problem of aircraft stall with pilots of the OV-1 aircraft indicated that it is not frequently encountered, because the aircraft is normally flown and landed at speeds well above stall speed. Currently, there is no stall sensor system on the OV-1. However, pilots indicated that there are many obvious warnings given by the aircraft prior to the actual stall. Based on this information, it was decided that the importance of the stall warnings should be moved below the fuel emergency warning.

e. Group 5

The arrangement of the emergencies within this group appeared to be consistent. These items were inserted as a group into the rankings.

f. Group 6

The final group of emergencies included emergencies which were of relatively low importance to the pilot either because of their nature or the fact that their characteristics are so obvious. These items were placed in the rankings as a group.

6. Summary

In trying to resolve the rankings within groups, the study team always attempted to examine all sources of evidence to achieve the best possible product. Where all rankings and other information agreed, resolution was, of course, quite simple. Otherwise, where the rankings disagreed, task analyses, operator's manuals, general questionnaires, and expert consultants were used to substantiate a specific resolution. Speed of response, as shown by the task analyses, was used as the major criteria for deciding the ranking between items which were relatively close in the priority sequence. However, task requirements, consequences of non-response, and requirements for information to be presented in a particular order were the major criteria used to establish the essential gross structure of the priority sequence. Once the initial ranking had been achieved for a given vehicle, the finally resolved list was re-examined for possible inconsistencies.

B. REVISIONS DUE TO VWS CHANNEL LIMITATIONS

MIL-R-81000(WEP) (Ref. 1) indicates that the VWS channel capacity is a set of 20 messages. However, the priority sequences established so far are much longer. Consequently, the VWS is not capable of presenting all the warnings which are necessary to present to the pilot; therefore, the visual-warning system must be referred to for the remainder. In reducing the length of the priority sequence to be compatible with VWS channel limitations, the priority sequence was sometimes changed slightly to include messages that the current visual-warning systems does not present. Therefore, all warnings are presented, but the VWS presents only the most critical messages. In many cases, it would be desirable to present two messages rather than one to give the pilot a more precise description of the fault (e.g., EGT high and EGT low, rather than just EGT), but channel limitations frequently prevented doing this.

Due to the lack of sensors for some emergencies, two lists of warnings were prepared. One list consists of those emergencies which would be desirable to present if the sensors were available. The other list consists of those warnings which could be implemented using the current sensor system.

To alert the pilot to emergencies which would not otherwise be included, the 20th message is "check caution panel." For all lists, this message was last.

1. UH-1

The list of warnings for the UH-1 is presented in Table 53. With a few minor exceptions, the list is taken directly from the resolved rankings. The warning for EGT was expanded into EGT low and EGT high

TABLE 53

Voice Warnings for UH-1*

Assuming Additional Sensors	Sensors Available
1. Fuselage fire	1. Blank channel
2. Engine fire	2. Engine fire
3. Engine failure	3. Engine failure
4. Transmission oil pressure	4. Transmission oil pressure
5. Engine oil pressure	5. Engine oil pressure
6. Transmission oil temperature	6. Transmission oil temperature
7. Transmission chips	7. Transmission chips
8. EGT low	8. EGT low
9. EGT high	9. EGT high
10. Engine rpm low	10. Engine rpm low
11. Engine rpm high	11. Engine rpm high
12. Rotor rpm low	12. Rotor rpm low
13. Rotor rpm high	13. Rotor rpm high
14. Engine chips	14. Engine chips
15. Engine fuel pump	15. Engine fuel pump
16. Hydraulic system	16. Hydraulic system
17. Fuel boost	17. Fuel boost
18. Fuel low	18. Fuel low
19. Generator (d-c)	19. Generator (d-c)
20. Check caution panel	20. Check caution panel

*The precise message wording is shown in Chapter VIII (Table 44 or 45).

because the task analysis indicated the pilot may not have time to diagnose the exact nature of the failure before responding (the questionnaire data indicated that the pilots would want the VWS to indicate this information to them).

Engine rpm also was divided into two message for the same reasons. Rotor rpm was divided into two messages, based on fast task response speed and the questionnaire data. In the latter, the pilots indicated that they would want both high and low rotor rpm presented to them.

The warnings for hydraulic failure were included in a single message. The speed of response time and task difficulty indicated that reducing the number of warnings to a single message would not be detrimental.

Similarly, the warnings for left and right fuel boost were included in a single message. Again, the speed of response and task difficulty indicated that responses to these emergencies should not be affected because both items are included on the caution panel.

Fuselage fire was considered by the study team to be of such importance that it is recommended to keep the first channel of the VWS blank until fire sensors become available. The remainder of the items on this list are the same as on all subsequent lists.

2. AH-1G

The list of warnings for the AH-1G is presented in Table 54. This list is similar to the list for the UH-1 although some of the priorities are different.

Rotor rpm was divided into two messages. The task analyses for this emergency indicated that it required immediate response time and that the pilot would need to know whether rotor rpm was high or low so that the appropriate response could be initiated.

EGT was expanded into EGT low and EGT high because the task analyses indicated that the response time for this emergency was short enough and the consequences are severe enough in the single engine helicopter that dividing the warning was warranted. The pilots also indicated a desire to have both high and low information presented to them.

The same reasoning applied to engine N_1 rpm; therefore, this message also was expanded into two messages.

The warning for hydraulic system No. 2 and hydraulic system No. 1 was combined into a single message. The task analyses indicated that these two emergencies do not require fast response times nor do they have serious consequences.

TABLE 54

Voice Warnings for AH-1G*

Assuming Additional Sensors	Sensors Available
1. Fuselage fire	1. Blank channel
2. Engine fire	2. Blank channel
3. Engine failure	3. Engine failure
4. Transmission oil pressure	4. Transmission oil pressure
5. Rotor rpm low	5. Rotor rpm low
6. Rotor rpm high	6. Rotor rpm high
7. Engine oil pressure	7. Engine oil pressure
8. Transmission oil temperature	8. Transmission oil temperature
9. EGT low	9. EGT low
10. EGT high	10. EGT high
11. Engine N_1 rpm low	11. Engine N_1 rpm low
12. Engine N_1 rpm high	12. Engine N_1 rpm high
13. Engine fuel pump	13. Engine fuel pump
14. Transmission chips	14. Transmission chips
15. Engine chips	15. Engine chips
16. Engine oil bypass	16. Engine oil bypass
17. Transmission oil bypass	17. Transmission oil bypass
18. Hydraulic system	18. Hydraulic system
19. Fuel boost	19. Fuel boost
20. Check caution panel	20. Check caution panel

*The precise message wording is shown in Chapter VIII (Table 44 or 45).

The warnings for aft and forward fuel boost were combined into a single message since the speed of response did not require two messages; in addition, only a single channel remained.

It is recommended that the first and second channels be left blank until the fire sensor systems for the engine and fuselage become available. The remainder of the items on the list are the same.

3. CH-47

The many critical emergencies for the CH-47 and the fact that the vehicle is a multi-engined aircraft required that many compromises be made in the specification of the required messages. The list of messages is shown in Table 55.

Double hydraulic system failure was presented at the top of the list because it was warranted by the task analyses and the pilot opinion data. It was thought that although the emergency is normally a fatal occurrence, sufficient warning might enable the pilot to attempt to maneuver the aircraft into a better altitude so that survival chances are increased.

The engine fire warning was divided into two warnings, based on the task data. The response times indicated for this emergency appear to be very short. Thus, it was determined that the voice warning should indicate which of the two engines was on fire.

Engine failure was divided into two messages, based on the task information and the pilot opinion data. The emergency was ranked high enough in the priority list that it was considered important to tell the pilot which of his engines had failed.

The limitations imposed by the system required that only a single message be given for EGT No. 1 engine, EGT No. 2 engine, N_1 rpm No. 1 engine, and N_1 rpm No. 2 engine. Examining the task analysis indicated that it would be highly desirable to tell the pilot both high and low for each of these messages. However, a compromise had to be made for this warning.

The reaction time required for rotor speed and the task requirements indicated that it was necessary to tell the pilot that rotor speed was either high or low. Thus, two messages were made for this warning.

Channel limitations and the task response speed indicated that a single message for engine oil pressure would be sufficient.

The high priority of the fuselage fire and the low visibility of the fuselage of the CH-47 indicated that this warning is highly desirable. Therefore, it is recommended that until sensors for this emergency are available, the channel should be left blank. The other warnings for both lists are the same.

TABLE 55

Voice Warnings for CH-47*

Assuming Additional Sensors	Sensors Available
1. Double hydraulic system	1. Double hydraulic system
2. Fuselage fire	2. Blank channel
3. Engine fire No. 1 engine	3. Engine fire No. 1 engine
4. Engine fire No. 2 engine	4. Engine fire No. 2 engine
5. Engine failure No. 1 engine	5. Engine failure No. 1 engine
6. Engine failure No. 2 engine	6. Engine failure No. 2 engine
7. Transmission oil pressure	7. Transmission oil pressure
8. Transmission chip	8. Transmission chip
9. Transmission oil temperature	9. Transmission oil temperature
10. Hydraulic system	10. Hydraulic system
11. Engine chips	11. Engine chips
12. EGT No. 1 abnormal	12. EGT No. 1 abnormal
13. EGT No. 2 abnormal	13. EGT No. 2 abnormal
14. N_1 rpm No. 1 engine	14. N_1 rpm No. 1 engine
15. N_1 rpm No. 2 engine	15. N_1 rpm No. 2 engine
16. Rotor speed low	16. Rotor speed low
17. Rotor speed high	17. Rotor speed high
18. Overtorque	18. Overtorque
19. Engine oil	19. Engine oil
20. Check caution panel	20. Check caution panel

*The precise message wording is shown in Chapter VIII (Table 44 or 45).

4. CH-54

The warning list for the CH-54 required tradeoffs similar to those made to construct the list for the CH-47. The lists for the voice-warning messages are presented in Table 56. Of the five vehicles in the study, this aircraft had the longest list of emergencies.

Engine failure was divided into two different messages for this vehicle. For this aircraft, it was deemed extremely important to inform the pilot of which engine had failed. The task analyses and the operator's manual show that the reason for this importance relates to the operation of the hydraulic systems. The No. 1 engine drives the first stage hydraulic system. The second stage hydraulic system operates from the rotor system. No critical systems are operated by the No. 2 engine.

The similarity of response time and response requirements indicated that a single message could be presented for the transmission oil pressure and intermediate transmission oil pressure emergencies. In the resolved list of emergencies, these two emergencies have very close priorities; also, the parameter of pressure is the same for both. Further clarification of the problem is presented on the annunciator panel where the specific problems are defined.

Since the hydraulic systems for this aircraft are operated by different pieces of equipment, it was considered necessary to inform the pilot which system had failed. The pilot opinion data also indicate that the pilots want the VWS to inform them which system has failed.

The warnings for the engine failures and the hydraulic system failures were rearranged, based on the rankings of the study team and the task analyses. These data indicated that No. 1 engine should be placed first. The first stage hydraulics system should be next, followed by the second stage hydraulics system. The No. 2 engine failure was placed after the second stage hydraulic system.

The N_2 flex cable emergency was divided into two warnings, based on the task requirements and the speed of response. It would be desirable for this warning to tell the pilot which engine has the emergency because it is often difficult for pilots to make this discrimination.

Engine fuel control malfunction was left as a single warning. The task analyses indicated that the speed of response for this malfunction would make it desirable to present two warnings so that the pilot would be immediately aware of the engine having the malfunction; however, space limitations indicated that this would not be practical.

TABLE 56

Voice Warnings for CH-54*

Assuming Additional Sensors

1. Fuselage fire
2. No. 1 engine fire
3. No. 2 engine fire
4. Transmission oil pressure
5. Transmission oil temperature
6. No. 1 engine failure
7. First stage hydraulics
8. Second stage hydraulics
9. No. 2 engine failure
10. Overtorque
11. N_2 flex cable failure No. 1 engine
12. N_2 flex cable failure No. 2 engine
13. Engine fuel control malfunction
14. Chip detector
15. EGT No. 1 engine
16. EGT No. 2 engine
17. N_1 rpm No. 1 engine
18. N_1 rpm No. 2 engine
19. Engine oil pressure
20. Check caution panel

Sensors Available

1. No. 1 engine fire
2. No. 2 engine fire
3. Transmission oil pressure
4. Transmission oil temperature
5. No. 1 engine failure
6. First stage hydraulics
7. Second stage hydraulics
8. No. 2 engine failure
9. Overtorque
10. Chips detected
11. EGT No. 1 engine
12. EGT No. 2 engine
13. N_1 rpm No. 1 engine
14. N_1 rpm No. 2 engine
15. Engine oil pressure
16. Rotor rpm low
17. Rotor rpm high
18. Fuel boost
19. Torque difference
20. Check caution panel

*The precise message wording is shown in Chapter VIII (Table 44 or 45).

The final items placed on the list were EGT No. 1 engine, EGT No. 2 engine, N_1 rpm No. 1 engine, and N_1 rpm No. 2 engine. These items were not divided into high or low messages due to the lack of channels.

For the second list, fuselage fire was not placed on the list, nor was a blank channel proposed. Instead, this item should remain optional. The emergency does require a very fast response time. At the same time, visibility of the fuselage area is excellent for the crew. To be more practical, there were important failures which were omitted from the other list due to channel limitations.

Moving other items to fill the channels created by the deletion of fuselage fire, N_2 flex cable, and engine fuel control emergencies created space at the bottom of the list for engine oil pressure, rotor speed abnormal, and fuel boost emergencies. The engine oil pressure warning was not divided because the response time for this emergency was sufficient for the pilot to analyze the problem. The response time for rotor speed abnormal indicated that the warning should show low or high rotor rpm; therefore, this warning was divided. Fuel boost pump was placed on the only remaining channel.

5. OV-1

Warnings for electrical fire and wing fire were eliminated from the list of emergencies for this aircraft due to the lack of sensors or the impracticality of placing sensors. The priority list for the OV-1 is shown in Table 57.

The fire warnings were presented for both engines. The task analyses indicated a very short response time for this emergency.

Double engine failure was not included in the list since this emergency is obvious to the pilot. It was thought that the presentation of engine failure for No. 1 engine and No. 2 engine would be sufficient.

The EGT warnings were not divided into high and low warnings so that adequate space would remain available for other warnings.

Engine fuel pump was given as a single message. Although there are engine fuel pumps for each engine, the task analyses did not show a requirement for individual warnings.

N_1 rpm was given for each engine. It would have been desirable to give either high or low, but the penalty in channel space did not warrant this division.

A single message for fuel metering control malfunction was considered adequate for this emergency even though there are two such devices on the aircraft.

TABLE 57

Voice Warnings for OV-1*

Assuming Additional Sensors	Sensors Available
1. Wheels	1. Wheels
2. Fuselage fire	2. Blank channel
3. No. 1 engine fire	3. No. 1 engine fire
4. No. 2 engine fire	4. No. 2 engine fire
5. No. 1 engine failure	5. No. 1 engine failure
6. No. 2 engine failure	6. No. 2 engine failure
7. EGT No. 1 engine	7. EGT No. 1 engine high
8. EGT No. 2 engine	8. EGT No. 1 engine low
9. Engine fuel pump	9. EGT No. 2 engine high
10. N_1 rpm No. 1 engine	10. EGT No. 2 engine low
11. N_1 rpm No. 2 engine	11. Engine fuel pump
12. Engine fuel metering control malfunction	12. N_1 rpm No. 1 engine
	13. N_1 rpm No. 2 engine
13. Engine oil pressure	14. Engine oil pressure
14. Fuel pressure	15. Fuel pressure
15. Hydraulic pressure	16. Hydraulic pressure
16. Engine chips	17. Engine chips
17. Fuel low	18. Fuel low
18. Fuel boost	19. Fuel boost
19. Fuel strainer	20. Check caution panel
20. Check caution panel	

*The exact message wording is shown in Chapter VIII (Table 44 or 45).

It is recommended that the channel for fuselage fire be left blank until this sensor is available. This emergency is of such extreme importance that such a system should be implemented.

On the second list, EGT was divided into high and low messages for each engine. It was decided by the study team that it was more important to the pilot to include this information instead of adding other less important items to the list.

Both lists of voice-warning messages are presented in Table 57.

C. SENSOR REQUIREMENTS

The heart of any warning system is the sensor system used to trigger the messages. In the VWS specification of the messages for the system, a few guidelines should be furnished relative to the sensor requirements.

1. Sensitivity of Sensors

Sensitivity for sensors was not a direct issue in this study. However, the problem was implied throughout the program. What is the proper degree of sensitivity for a sensor such that the sensor provides adequate warning sufficiently early without a high number of "false alarms?" Based on the literature of human and animal learning, if a stimulus is presented too often without reinforcement, then the stimulus loses its power to evoke a response. Applied to the current situation, this would indicate that if the false alarm rate for messages or a given message was overly high, then the pilot would probably start ignoring the warning rather than responding to it.

As new sensors are developed, many messages will become feasible which are not currently on the list of messages. Inserting these warnings into the list should not impose any problem because the priority list is provided.

If the present VWS is expanded, it is recommended that great caution be exercised in adding new messages to the system. Messages having to do with the status of ground equipment, switch positions, or low priority could quickly cause the VWS to lose its effectiveness due to nuisance warnings coming on the system. One of the strong points of the VWS is its uniqueness as a warning device. However, should the warning device come on too frequently, then this distinctiveness will be lost.

2. Engine Failure

It is recommended that the warnings for engine failure must sense EGT, torque, rpm, and throttle position. The EGT and rpm settings for these sensors should be other than the sensors used for single EGT

and rpm messages, which are ranked below engine failure. The purpose of recommending that throttle position be sensed is to avoid false messages during engine shutdown or when power is removed from an engine.

3. Locking Out Superfluous Messages

When some vehicle systems fail, other systems may be affected, resulting in a number of voice-warning messages emanating from a single failure. For example, when the engine fails, a number of related parameters are affected, so that first "engine failure" is announced and repeated until the pilot over-rides the VWS, and then "EGT low," "N_1 low," etc. are announced, requiring the pilot to over-ride each. In the midst of an emergency, then, the pilot may be forced to listen to a number of messages and over-ride each, even though he knows that these systems are failed as a result of a primary failure. The pilot also is given a list of the failed systems on the annunciator panel. As a consequence, it is thought very desirable to arrange the logic of the VWS so that such superfluous messages do not degrade pilot performance. This may be performed by arranging so that a given fault (e.g., engine failure) prevents (or locks out) other messages from being announced (e.g., EGT, rpm, engine-driven pump, generator, etc.).

For the UH-1, the single messages for EGT, engine rpm, engine oil pressure, engine fuel pump, d-c generator, and other engine-related systems should be locked out of the VWS in the event of engine failure.

In the AH-1G, the single messages for engine oil pressure, EGT, engine rpm, engine fuel pump, and other engine-related systems should be locked out of the VWS in the event of engine failure.

In the cases of the CH-47 and CH-54, some very critical systems may be failed as a result of engine failure. Although engine failure normally requires the pilot to land immediately, circumstances of terrain or being over enemy territory may prevent this response. Therefore, where the engine failure results in the failure of a critical system (such as hydraulic systems), the pilot probably should be informed of the problem. For these aircraft, messages which should be locked out are those single messages for EGT and engine rpm on the failed engine, engine oil, engine fuel control, engine fuel pressure, generators, and other related systems operated by the failed engine.

On the OV-1, the single messages for EGT and rpm on the failed engine, engine oil pressure, fuel pressure (if affected), engine fuel pump, engine fuel metering control, and other engine-related systems should be locked out of the VWS in the event of engine failure.

4. EGT and RPM Warnings

It is recommended that these warning sensors be set at tolerances closer to normal operating values than the corresponding sensors for engine failure.

5. Fuel Boost Pump

For several of the aircraft in the study, the warning list included fuel boost pump. There normally are two boost pumps per fuel tank on most of these vehicles. It is recommended that the fuel boost warning be given when a single pump fails. On one aircraft, the OV-1, the current visual system does not light until both pumps in a fuel tank have failed. Pilots have complained that this warning is "after the fact." It is suggested that, if the VWS is to serve as a preventative tool, warnings must be given in sufficient time for the pilot to correct the situation.

6. Chip Detection

Many of the pilots interviewed during the study indicated general displeasure with chip detectors. However, the questionnaire indicates the chip detector should be included even though the false alarm rate is high. Further study should be given to the desired sensitivity of the sensors for this warning.

7. Wheels

This warning is on the list of messages for the OV-1. It is recommended that the sensor be triggered by airspeed and radar altitude. The current wheels warning light is given only if the flaps are set at 15 degrees or more. For no-flap landings, the warning would not be given. It is further recommended that the sensors for this warning should sense not only that the landing gear has not been lowered, but also if it is not safely locked.

8. Transmission Oil Pressure

For the CH-54 only, the sensors for transmission oil pressure and intermediate transmission oil pressure should provide one message—transmission oil pressure.

D. MESSAGE CONTENT

The VWS is an auditory display, and the messages recorded are the information that may be conveyed to the pilot. A first consideration is that the pilot hear the messages or, if he does not hear them clearly, that he is at least alerted to any failure which may exist. Secondly, he should not confuse one message with another, or he may make matters worse by making the wrong response. Thirdly, the messages should present the information he needs, in the right form, and in the right amount to take the proper initial action.

1. Alerting Signal

It is believed that VWS messages should begin with an alerting signal for the purposes of the Army aircraft considered in this study. These vehicles have high noise environments. The alerting signal can be tailored to the noise spectra, and, consequently, there is a higher probability that the alerting signal will be heard than for the speech components of the message. Without the alerting signal, the pilot may not direct his attention to the speech component at first; hence, there is a possibility that the pilot may hear later parts of the announcement but not the first. This may lead to confusion, or may cause the pilot to wait until the announcement is repeated, causing unnecessary delay.

2. Message Discrimination

Chapter VIII describes an investigation that was made to determine a set of messages which would be easily discriminated from each other. The message style chosen is one in which the first word of each message is different, and attempts are made to make each message as different as possible. With training, it will be possible for the pilot to take correct action when just the first word is heard (speeding his response), or perhaps even when parts of the message are heard.

After the alerting signal, the message is repeated at least four times within the 15-second tape, but the alerting signal may be only recorded at the beginning of the tape. In this manner, if a higher priority message interrupts another message while it is playing, it should be clear that a new message has begun. Otherwise, confusion between messages is possible. Repeating each message four times within the tape duration may be found to be annoying to pilots when they can hear the messages clearly, for the message will continue to play until the pilot over-rides the VWS or until the fault is corrected. Nevertheless, rapidly repeated messages are considered necessary in the high noise environments of these vehicles. The pilots report that they must frequently request that transmissions be repeated (Table 33); it must, therefore, be concluded that they may frequently not hear the VWS correctly the first time. Moreover, the messages must be repeated to cause the pilot to over-ride the system as soon as possible, because other low priority faults also may have occurred.

3. Message Content

The messages which were created in this study are very brief. An attempt was made to minimize the vocabulary used (and, consequently, message length) to increase discriminability between messages. However, another reason was that it was desired to only indicate the nature of the fault in a clear and succinct form. No elaboration on the nature of the fault or possible corrective action to be taken was considered

advisable. The questionnaire survey clearly indicates that the pilots do not want to be told what response to take. The task analyses conducted indicate that it is seldom possible to tell the pilot the exact nature or degree of the fault, and that his response should depend on a number of conditions which would not be known until the time of the emergency. It would not be possible to precisely decide what to do in advance, and it would not be possible to put such information into the VWS messages.

4. Message List

Lists of messages are presented in Tables 44 and 45; these are composites of all the messages considered for the six vehicles of this study. A selection of these, placed in the proper priority sequence, will suffice for any of the vehicles.

5. Additional Research

The current recommendations are based on careful consideration of the discriminability of VWS, including pilot judgments and word discrimination tests. It is possible that improvements in the current message lists could be derived in sufficient formal research, using large groups of subjects.

E. COCKPIT INTEGRATION

An analysis of the current instrument panel displays leads to the conclusion that the only displays which did not present additional information to the VWS, and which overlapped in function with the VWS, were the displays associated with the visual-warning system. Thus, the search for visual displays which might possibly be removed led directly to the problem of the relationship between the visual- and voice-warning systems.

The study of the noise environments associated with the vehicles for which noise data existed showed that the noise levels were very high. In fact, to increase the VWS output to achieve a signal-to-noise ratio which would give good detectability caused sound pressure levels which would endanger the ears of the pilots. One possible measure for protecting the pilots' ears, while maintaining an acceptable signal-to-noise ratio, is for the pilots (and other crew members) to wear earplugs. In view of these noise levels and the number of communications which may be simultaneously monitored, it appears that the VWS may not always be heard. Thus, there is a need to maintain the visual-warning system as a backup for the VWS (if for no other reason).

Additionally, the number of channels is limited on the VWS, so there are low-importance warnings which will not appear explicitly via the VWS, and, in some cases, the warnings on the VWS may not give

information as detailed as that displayed on the visual caution panel. The result is that the visual- and voice-warning systems should be used together, as redundant systems, to take the best advantage of each.

The VWS is a new system to be added to an already existing display system. It would be desirable to integrate the warning systems into an effective unit, but this will not be possible without modifying the existing visual-warning system. For example, the visual-warning system incorporates a master caution light, and the VWS is recommended to use an alerting signal. Because the same alerting signal will appear with each of the VWS messages, it becomes the counterpart of the master caution light. However, the alerting signal and the master caution light will not be associated with the same warnings. Some warnings will appear on the VWS which are not currently sensed for the visual warning system; other warnings will appear on the visual system, but will not appear on the VWS because of the lack of message channels or the low importance of the fault. Furthermore, it would degrade the effectiveness of the VWS if warnings were included for nuisance faults.

On the other hand, steps may be taken to improve the combined operation of the warning systems. For example, operation of the warning systems would be eased if the warning system controls were combined. A single reset control for both visual- and voice-warning systems would ease operation and facilitate pilot acceptance. The visual-warning system should show the status of the VWS, because, if the pilots are to be allowed to disable the voice warning system (which may cause difficulties), a reminder is necessary that the VWS is off.

X. RECOMMENDATIONS

As a result of the analyses performed in this study, a number of recommendations were derived for the application of the VWS to the Army aircraft concerned. These detailed recommendations are summarized in the following paragraphs.

1. Priority Sequence

A priority sequence was established for each vehicle. Because, in most cases, more warnings were involved than there were channels on the VWS, some low-priority faults were not assigned explicit messages. Moreover, the inclusion of some messages would require sensors that are not immediately available; therefore, more than one priority sequence was developed for each vehicle. The recommended priority sequences are shown in Tables 53 through 57 (pages 117, 119, 121, 123, and 125) and discussed in Chapter IX.

2. Message List

Based on criteria of maximum audibility, intelligibility, and discrimination between messages, two lists of messages were derived. Message discrimination tests favor the list in Table 44 (page 87); this is the recommended list. The other list, however, conforms closely to to MIL-STD-411C; it is given as an alternate recommendation in Table 45 (page 89). The lists are composite lists of the messages for all vehicles. The messages should be selected from the composite list and ordered to the appropriate recommended priority sequence for each vehicle.

3. Message Structure

The recommended message structure is an alerting signal followed by the appropriate message repeated at least four times as follows: (1) alerting signal (0.5-second duration), (2) message (from message list, Tables 44 or 45), (3) silence (0.5 second), (4) message, (5) silence, (0.5 second), (6) message, (7) silence (0.5 second), (8) message, (9) silence (0.5 second), and (10) depending on the length of the message, repeat alerting tone and sequence from (1), as long as at least one full message may be announced in the time remaining on the 15-second tape.

4. Alerting Signal

Based on the available data, it is believed that an alerting signal with the following characteristics will be adequate: (1) 0.5-second duration, (2) pure sinusoidal tone (2500 Hz), (3) a 10-db level, or more, above competing ambient sound pressure levels.

5. Future Expansion of VWS

If the present VWS is expanded, it is recommended that great caution be exercised in adding new messages to the system. Messages concerning the status of ground equipment, switch positions, or low priority could cause the VWS to quickly lose its effectiveness because of nuisance warnings coming on the system. One of the strong points of the VWS is its uniqueness as a warning device; however, should the warning device come on too frequently, then this distinctiveness will be lost.

6. Voice Quality

Based on considerations of vehicle noise characteristics, it is recommended that a female voice be used; however, detailed speech intelligibility tests should be performed on a number of candidates before final selection of the individual voice. The announcer should be well-practiced and coached in specific delivery techniques and emphasis of individual messages.

7. VWS Output Control

The VWS output should be maintained at a level of 10 db or more above ambient noise levels. At maximum noise levels, the combined VWS and noise sound pressure will be so great that the crew will need earplugs to avoid permanent ear damage. Also, an automatic level control will be needed to lower VWS output for low noise levels; otherwise serious startle effects may hamper pilot response.

8. Removal of Visual Displays

The investigations conducted did not reveal a basis for recommending the removal of any of the cockpit visual displays in any of the vehicles. Some low-importance displays were noted, but addition of the VWS did not provide reason for their removal.

9. Integration of Warning Systems

This study concluded that the visual- and voice-warning systems should be used together as redundant cross-checking systems. The integration of these systems into a composite warning system deserves additional study. The operating controls for the two warning systems should be integrated, so that single controls operate the visual- and voice-warning systems where applicable.

XI. REFERENCES

1. Military Specification, Reproducer Set, Voice Warning, U.S. Navy MIL-R-81000 (WEP), AN/ASH-19(*), 18 February 1964.

2. A. A. Burrows and M. N. Travis, Aircraft Warning, Cautionary and Advisory Systems, ASCC W.P. 10, Project 3, RAF Institute of Aviation Medicine, 1959.

3. A. A. Burrows, "Aircraft Warning Systems: Argument, Evidence, and Design," 15th IATA Technical Conference, Lucerne, Switzerland, Douglas Aircraft Company, Engineering Paper No. 1587, 1963.

4. Dwight E. Erlick and Darwin P. Hunt, Evaluating Audio Warning Displays for Weapon Systems, WADC Technical Report No. 57-222, ASTIA Document 118189, U.S. Air Force, Aerospace Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, April 1957.

5. J. C. R. Licklider, Audio Warning Signals for Air Force Weapon Systems, WADD Technical Report No. 60-814, Contract No. AF33(616)-5611, Bolt, Beranek, and Newman Inc., Behavioral Sciences Laboratory, Aerospace Medical Laboratory, Wright Air Development Command, U.S. Air Force, Wright-Patterson Air Force Base, Ohio, March 1961.

6. A. Mikk and T. S. Bragg, Human Engineering Evaluation of Nortronics Voice Warning System (NORVIPS), Letter Report No. 23, Systems Research Laboratory, USAHEL, Aberdeen Proving Ground Maryland, February 1966.

7. Lt. Col. Clement A. Wyllie, "Voice Warning Systems for Army Aircraft," Army Aviation Digest (in press), 1966.

8. Earl B. Smith, Military Potential Test of the AN/ASH-19 Voice Warning System and Continuous In-Flight Performance Recorder, Final Report of Test, Department of the Army, U.S. Army Aviation Test Board, Fort Rucker, 31 March 1966.

9. Consolidation of B-58 Voice Warning System (VWS) Crew Questionnaires, Directorate of Aerospace Safety, Norton Air Force Base, July 1967.

10. Harold E. Price and Harry J. Older, Auditory Signals in Air Force Weapons Systems and Equipment, PRA Final Report No. 56-11, Contract No. AF19(604)-1576, Operational Applications Laboratory, Psychological Research Associates, Washington, D.C., June 1956.

11. T. S. Bragg, Acoustical Study of the CH-47B Helicopter, Letter Report No. 59, Acoustical Research Branch, Engineering Research Laboratory, USAHEL, Aberdeen Proving Ground, Maryland, June 1967.

12. Military Standard, Air Crew Station Signals, MIL-STD-411C, Department of Defense, 21 August 1967.

13. Military Standard, Human Engineering Design Criteria for Aerospace Systems and Equipment, Part 2: Aerospace System Facilities and Facility Equipment, MIL-STD-803A-2, U.S. Air Force, 1 December 1964.

14. M. Woodhead, Effects of Bursts of Loud Noise on a Continuous Visual Task, RNP No. 57/891, Royal Navy, 1957.

15. Military Standard, Human Engineering Design Criteria for Aerospace Systems and Equipment, Part 1: Aerospace System Ground Equipment, MIL-STD-803A-1, U.S. Air Force, 24 January 1964.

16. R. J. Camp Jr. and R. L. Keiser, Sound Attenuation Characteristics of the Army APH-5 Helmet, Report No. 67-6, USAARU, 1967.

17. M. Rappaport, "Increasing Voice Communication Channels Using Man's Binaural Listening Capability," Human Factors Journal, Vol. 7, No. 1, pp 28-37, February 1965.

18. I. Pollack and J. M. Pickett, "Stereophonic Listening and Speech Intelligibility Against Voice Babble," Journal of Acoustic Society of America, Vol. 30, pp 131-133, 1958.

19. C. Cherry, On Human Communication, John Wiley & Sons, New York, 1957.

20. G. N. Traul and J. W. Black, "The Effect of Context on Aural Perception of Words," Journal of Speech and Hearing Research, Vol. 8, pp 363-369, 1965.

21. G. A. Miller, et. al., "The Intelligibility of Speech as a Function of the Context of Test Materials, Journal of Experimental Psychology, Vol. 41, pp 329-335, 1951.

XII. SELECTED BIBLIOGRAPHY

1. N. H. Azrin, Some Effects of Noise on Human Behavior, U.S. Army Technical Memorandum 6-58, Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, OCO, Research Branch, Project No. TB1-1000, June 1958.

2. Almon J. Bate and Charles Bates, Jr., A Comparison of Cockpit Warning Systems, Contract No. AMRL-TR-66-180, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, April 1967.

3. J. E. Beaupeurt, "A Study of the Effects of Vibration on Human Performance," Naval Research Review, August 1962.

4. L. J. Berenak, Noise Reduction, McGraw Hill Book Company, New York, 1960.

5. R. T. Camp Jr., Real-Ear Sound Attenuation Characteristics of Thirty-Six Ear Protective Devices, USAARU Report No. 66-6, U.S. Army Aero Medical Research Unit, Fort Rucker, Alabama, May 1966.

6. William P. Christian and Major Robert W. Newton, CH-47 Accident Summary, USABAAR, Fort Rucker, Alabama, 1 July 1962 through 30 June 1966.

7. William P. Christian, OV-1 Accident Summary, USABAAR, Fort Rucker, Alabama, 1 July 1963 through 30 June 1966.

8. Robert D. Dean and Carl L. McGlothlen, "Effects of Combined Heat and Noise on Human Performance, Physiology, and Subjective Estimates of Comfort and Performance," presented at the Institute of Environmental Sciences, 1965 Technical Meeting and Equipment Exposition, Chicago, Illinois, Engineering Psychology Bioastronautics, Aerospace Technologies, Aero Space Division, The Boeing Company, 1965.

9. D. B. Devoe, Integration of Concurrent Visual and Auditory Messages, Report No. ESD-TR-65-461, Contract No. AF19(628)-4073, Sylvania Electronic Systems, Waltham, Massachusetts, Decision Sciences Laboratory, Electronic Systems Division, Air Force Systems Command, United States Air Force, L. G. Hanscom Field, Bedford, Massachusetts, October 1965.

10. Paul D. Engelder and Douglas A. Moore, Signal, Warning, Multiple for Headset, WADC Technical Report No. 59-343, Air Material Command Contract No. AF33(600)-37155, Project No. 8(1-6190)-60534, Wright Air Development Center, Air Research and Development Command, United States Air Force, Wright-Patterson Air Force Base, Ohio (performed under Contract by Nortronics Division of Northrop Corporation, Hawthorne, California), June 1959.

11. Jennie Gatti, Reports of Research in the Field of Engineering Psychology, WADC Technical Report No. 56-154, Wright Air Development Center, Air Research and Development Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, April 1956.

12. W. F. Glasea, "The Why and How of Noise Control," Safety Maintenance Magazine, July-August 1961.

13. W. J. Grant, A Study to Correlate Flight Measured Helicopter Vibration Data and Pilot Comments, WADD Technical Report No. 61-66, Air Force Contract No. AF33(616)-5240, Aeronautical Systems Division, United States Air Force, Wright-Patterson Air Force Base, Ohio (performed under Contract by Vertol Division, Boeing Airplane Company, Morton, Pennsylvania), August 1961.

14. J. C. Guignard, "Effects of Vibration on Man," Journal of Environmental Sciences, Vol. 9, No. 4, pp 29-32, August 1966.

15. C. M. Harris, Handbook of Noise Control, McGraw Hill Book Company, New York, 1957.

16. N. W. Heimstra, N. B. Louis, and Major Arnold R. Young, Survey of Operational Flying Activities of Rotary Wing Aviators, HumRRO Technical Report No. 75 (AD 274 980), Contract No. DA44-188-ARO-2, U.S. Army Aviation Human Research Unit, Fort Rucker, Alabama (under the technical supervision of the George Washington University Human Resources Research Office under Contract with the Department of the Army), April 1962.

17. R. H. Henneman, et. al., The Influence of the Sensory Requirements of the Distracting Task (the first of a series of reports on auditory and visual message presentation under distracting task conditions), WADC Technical Report No. 53-309, Contract No. W33-038-ac-21269, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, University of Virginia, Charlottsville, Virginia, Aero Medical Laboratory, November 1953.

18. R. H. Henneman and Thomas L. Matthews, The Influence of Message Length and Distracting Task Complexity (the second in a series of reports on auditory and visual message presentation under distracting task conditions), WADC Technical Report No. 54-145, Contract No. W33(038)-ac-21269, Wright Air Development Center, Air Research and Development Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, University of Virginia, Aero Medical Laboratory, April 1955.

19. H. H. Holland, Jr., "Attenuation Provided by Fingers, Palms, Tragi, and V51R Ear Plugs," The Journal of the Acoustical Society of America, Vol. 41, No. 6, 1967.

20. W. C. Howell and George E. Briggs, Information Input and Processing Variables in Man-Machine Systems: A Review of the Literature, Technical Report No. NAVTRADEVCEN 508-1, Contract No. N61339-508, U.S. Naval Training Device Center, Port Washington, New York, Ohio State University, 26 October 1959.

21. Dr. Lyle V. Jones, Methodology of Preference Measurement, Final Report No. 4, Contract No. DA19-129-QM-774, P1101, Quartermaster Food & Container Institute for the Armed Forces, Research and Engineering Command, Quartermaster Corporation, U.S. Army, Chicago, Illinois, 1 October 1956 to 30 September 1957.

22. J. C. Kelly, et. al., Syllable Duration and Intensity Related to Intelligibility, Purdue University, 1949.

23. George L. Kreezer, Attention Value of Audio and Visual Warning Signals, WADC Technical Report No. 58-521, ASTIA Document No. AD 278 885, Contract No. AF33(616)-135, United States Air Force, Aero Medical Laboratory, Wright-Patterson Air Force Base, Ohio, Department of Psychology, Washington University, April 1959.

24. K. D. Kryter, "Hazardous Exposure to Intermittent and Steady State Noise," NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics, January 1965.

25. K. D. Kryter, Review of Research and Methods for Measuring the Loudness and Noisiness of Complex Sounds, NASA CR-422, Contract No. NASw-1102, prepared by Bolt, Beranek, and Newman, Inc., Cambridge, Massachusetts, for National Aeronautics and Space Administration, Washington, D.C., April 1966.

26. Martin I. Kurke, "Operational Sequence Diagrams in System Design," Human Factors, Vol 3(1), pp 66-73, March 1961.

27. Robert K. Cassatt, Missions Analysis for OV-1 Mohawk Aircraft, Technical Memorandum No. 13-64, Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, November 1964.

28. Kenneth L. Mattox, Injury Experience in Army Helicopter Accidents, ASTIC No. AD658 079, Human Factors and Prevention Division, HF 68-1, USABAAR, Fort Rucker, Alabama, 1967.

29. A. Mirabella and D. A. Goldstein, "The Effects of Ambient Noise Upon Signal Detection," Human Factors, Vol. 9, No. 3, 1967.

30. A. P. Peterson and E. E. Gross, Jr., Handbook of Noise Measurement, General Radio Corporation, 1963.

31. L. T. Pope, Attention Level and Visual and Auditory Monitoring Performance, Report No. AMRL-TDR-62-97, Project No. 7184, Task No. 718406, Behavioral Sciences Laboratory, 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, August 1962.

32. M. Rappaport, Simultaneous Messages with But Two Ears, unpublished report, Agnews State Hospital, San Jose, California, 1961.

33. M. Rappaport, "Increasing Voice Communication Channels Using Man's Binaural Listening Capability," Human Factors, Vol. 7, No. 2, pp 28-37, February 1965.

34. M. Rappaport, et. al., "Comparative Ability of Normal and Chronic Schizophrenic Subjects to Attend to Competing Voice Messages: Effects of Method of Presentation, Message Load, and Drugs," Journal of Nervous and Mental Disease, Vol. 143, No. 1, pp 16-27, 1966.

35. W. A. Rosenblith and K. N. Stevens, Handbook of Acoustic Noise Control, Volume II: Noise and Man, WADC Technical Report No. 52-204, Contract No. AF33(038)-20572, Wright Air Development Center, Air Research and Development Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, Bolt, Beranek, and Newman, Inc., Aero Medical Laboratory, June 1953.

36. R. W. Schoenberger and C. S. Harris, Human Performance as a Function of Changes in Acoustic Noise Levels, AMRL Report No. TR 65-165, December 1965.

37. A. L. Siegel, "Information Transfer in Display-Control Systems" (editor), Applied Psychological Services, March 1964.

38. E. Spezia, Role of Pilot Factors in Army Fixed Wing Accidents, Report No. HF 1-62, Analysis and Research Division Human Factors Section, U.S. Army Board for Aviation Accident Research, Fort Rucker, Alabama, January 1962.

39. E. Spezia, Role of Pilot Factors in Army Helicopter Accidents, Report No. HF 2-62, Analysis and Research Division Human Factors Section, U.S. Army Board for Aviation Accident Research, Fort Rucker, Alabama, January 1963.

40. C. D. Taffe and H. H. Jones, Noise and Hearing, U.S. Department of Health, Education, and Welfare, Washington, D.C., 1961.

41. J. B. Thurmond, et. al., Factors Influencing Detection and Monitoring Performance, Sensory Research Laboratory, University of Louisville, 1967.

42. W. E. Williams and D. D. Young, An Evaluation of Four Methods of Monitoring Simultaneous Primary and Secondary Voice Messages, Philco Corporation, 1965.

43. Study of Communication in High-Level Ambient Noise Fields, Final Report, Contract No. DA-36-039-sc-64469, Phase I Noise analysis and Equipment Performance. Surface Communications Engineering, Defense Electronic Products, Radio Corporation of America, Camden, New Jersey, under Contract to U.S. Army Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey, Radio Corporation of America, 12 May 1955.

44. Study of Communication in High-Level Ambient Noise Fields, Project Nos. 132B, 843D, Contract No. DA-36-039-sc-64469, Sigel-CWB, Coles Signal Laboratory, Fort Monmouth, New Jersey, Radio Corporation of America, 1955.

45. Study of Communication in High-Level Ambient Noise Fields, Report Nos. 1 through 7, Contract No. DA-36-039-sc-64469, Coles Signal Laboratory, Fort Monmouth, New Jersey, Radio Corporation of America, 1955-1956.

46. Hazardous Noise Exposure, Air Force Regulation No. 160-3A, U.S. Air Force, Department of the Air Force, Washington, D.C., 27 June 1960.

47. Operational Test and Evaluation Verbal Warning System, Document No. TAC-TR-62-20, Tactical Air Command, U.S. Air Force, Langley Air Force Base, Virginia, June 1963.

48. Operator's Manual Models UH-1A and UH-1B Helicopters, Document No. TM 55-1520-211-10, Headquarters, U.S. Army, Washington, D.C., June 1967.

49. Operator's Manual Army Model AH-1G Helicopter, Document No. TM 55-1520-221-10, Headquarters, U.S. Army, Washington, D.C., April 1967.

50. Operator's Manual Army Models CH-47A and CH-47B Helicopter, Document No. TM 55-1520-209-10, Headquarters, U.S. Army, Washington, D.C., April 1967.

51. Operator's Manual Army Model CH-54 Helicopter, Document No. TM 55-1520-217-10, Headquarters, U.S. Army, Washington, D.C., 1967.

52. Operator's Manual OV-1 Aircraft, Document No. TM 55-1510-204-10 (with changes), Headquarters, U.S. Army, Washington, D.C., May 1967.

53. U.S. Army Optimum Instrument Presentation and Panel Arrangement for Army Rotary-Wing Aircraft, Report of Project No. NR AVN 457.8/59, U.S. Army Aviation Board, Fort Rucker, Alabama, 28 May 1958.

54. Aviator Capability Versus Workload, Army Aviation School, Fort Rucker, Alabama, 1959.

55. Mission Profiles, UH-1B, D (HU-1B, D) Iroquois, U.S. Army Combat Developments Command, Fort Rucker, Alabama, 1967.

56. Pilot's Checklist - OV-1, Document No. TM 55-1510-204-10 CL, U.S. Army, Fort Rucker, Alabama, August 1967.

57. Evaluation of and Proposed Specification for Voice Warning System for Use in Naval Aircraft, WEPTASK No. RAVorJ009/2021/F006-08-01, U.S. Navy, December 1963.

58. Evaluation of Nortronics Voice Interruption Priority System (NORVIPS), Final Report, Project No. ADC/73AD/62-31, 4750 Test Squadron (operational), 8 April 1963.

59. Handbook of Human Engineering Data, Second Edition (revised), NAVEXOS P-643, Tufts College, Institute for Applied Experimental Psychology, U.S. Naval Training Device Center, Port Washington, New York, November 1952 (reprinted January 1960).

60. An Evaluation Guide for Army Aviation Human Factors Engineering Requirements, HEL Standard S-5-65, Aviation Branch, Systems Research Laboratory, Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, November 1965.

61. U.S. Air Force Military Standard, Missile Systems Human Factors Engineering Criteria, MIL-STD-1248 (M1) Department of Defense, Washington, D.C., 20 January 1964.

62. Operator's and Crewmember's Checklist Army Models OV-1A, OV-1B, and OV-1C Airplanes, Observation STOL, Pilot's Checklist, Department of the Army Technical Manual No. TM 55-1510-204-10CL, Headquarters, U.S. Army, May 1967.

63. The Relations of Hearing Loss to Noise Exposure, Contract No. N5ori-07861, Exploratory Subcommittee Z24-X-2 of the American Standards Association (a report issued by Z24 Sectional Committee on Acoustics, Vibration, and Mechanical Shock), Acoustical Society of America, New York, 1954.

APPENDIX A

VEHICLE DESCRIPTIONS

A. UH-1B GENERAL DESCRIPTION

The UH-1B, designated as a utility helicopter, went into service in March 1961. It is powered by a single Lycoming T-53-L-11 1100 shaft-horsepower engine. It has a fuselage length of 42.6 feet, overall length of 53 feet, and a main rotor diameter of 44 feet. The normal gross weight for this vehicle is 8500 pounds, and its empty weight is 4519 pounds.

1. Performance Characteristics

The UH-1B has a maximum speed of 130 miles per hour, and a cruise speed of 108 miles per hour. Its normal range is 213 miles, and its rate of climb is 2350 feet per minute. The hovering ceiling is 16,800 feet (IGE) and 12,700 feet (OGE); the service ceiling is 16,700 feet. Its normal fuel capacity is 165 U.S. gallons.

2. Purposes

The UH-1B has been utilized in a variety of roles, including: freight carrying, troop delivery, medical evacuation, and gunship support of ground troops. In these roles, it has a capacity of: seven troops; three litters, two sitting casualties, and a medical attendant; or 3000 pounds of freight.

3. Crew Size

The crew consists of a pilot, copilot, and crew chief (who also functions as a gunner).

4. Armament

Various configurations have been adapted to the UH-1B; these include outrigger booms with 6 Nord SS.11 wire-guided anti-tank missiles, rockets, electronically controlled machine guns, and a turret-mounted 40mm grenade launcher on the nose.

5. Visibility

Pilot and copilot visibility is forward, sideways, and downward. They cannot see the fuselage behind or above them. In case of suspected fire or engine malfunction, the crew chief examines the area by hanging out the cargo doors on either side by the safety straps.

6. Audio-Warning Devices

Only one audio-warning device is now installed on the UH-1B. This signal is a buzz emitted in the headset whenever rotor rpm of 300 ± 5, or engine rpm of 6000 ± 100, or both are encountered.

7. Special Problems

Some of the special problems associated with this aircraft are presented in this appendix.

B. UH-1D GENERAL DESCRIPTION

The UH-1D, a more advanced version of the UH-1B which has been in service since June 1963, is considered to be a tactical transport helicopter. The UH-1D utilizes the same engine as its predecessor. The fuselage length for this version is 44.6 feet, overall length is 53.9 feet, and the main rotor diameter is 48 feet. The UH-1D has a normal gross weight of 9500 pounds and an empty weight of 4717 pounds.

1. Performance Characteristics

The UH-1D has a maximum speed of 138 miles per hour and a cruise speed of 135 miles per hour. Because of increased fuel capacity, its normal range is 315 miles. The rate of climb is 2350 feet per minute, with a hovering ceiling of 18,200 feet (IGE) and 14,000 feet (OGE). The service ceiling is said to be 22,000 feet, and the fuel capacity, normally is 220 U.S. gallons.

2. Purposes

The UH-1D is used in the same role as the UH-1B; however, because of the extended fuselage and rearrangement of the cabin, it can carry its crew plus 12 troops or six litters and a medical attendant, or 4000 pounds of freight.

3. Crew Size

Normally, the crew consists of a pilot, copilot, and crew chief.

4. Armament

The UH-1D has the same armament as the UH-1B.

5. Visibility

There is no appreciable change in visibility over the UH-1B; however, larger doors increase the outside view by the crew chief.

6. Special Problems (UH-1B and UH-1D)

Because the engines of these aircraft can turn out more power than the transmission is rated to receive, overtorquing of the transmission can occur.

Currently, there are no fuselage fire warnings for this vehicle. Fuselage fires are detected by having the crew chief lean out of the cargo doors to inspect the fuselage.

A number of pilots have indicated that tail rotor failures occur more frequently in these aircraft than in other aircraft.

Instances of engine failure have been reported in which the pilot was not aware of this failure for some time.

As with most single-engine aircraft, this vehicle does not have an engine fire extinguisher system.

It has been indicated that overloading of these aircraft in the field is currently quite a problem. This is especially true where the pilot is rushed during the loading of the aircraft and probably is compounded by the relative inexperience of the pilots.

Although not directly related to the UH-1 models under consideration, the hydraulics system of the UH-1C are necessary for flying the aircraft. Loss of both hydraulic systems in the "C" model is normally a fatal condition whereas, in the "B" and "D" models, it is not as catastrophic. Another problem in the "C" model which further complicates the seriousness of hydraulic failure, is the fact that the hydraulic reservoirs for both systems are sufficiently close together that a well-placed hit from gunfire can cause failure of both hydraulic systems.

Table 3 presents the UH-1 caution panel, and Figures 1 and 2 show the UH-1 vehicle and cockpit instrument panel, respectively.

C. AH-1G GENERAL DESCRIPTION

The AH-1G is a tactical helicopter with tandem two-place seating. It has a single 1400 shaft-horsepower engine, an overall length of 52.9 feet, and a rotor diameter of 44 feet. Its maximum gross weight is 9500 pounds.

1. Performance Characteristics

The AH-1G is a high-speed tactical gunship designed for combat missions. The maximum speed is 190 knots per hour, and the cruise speed is 149 knots per hour. The normal range is reported to be more than 500 miles. This vehicle has a hovering ceiling of 16,000 feet and a rate of climb of 1990 feet per minute.

2. Purposes

This vehicle was designed as a tactical helicopter for the purpose of providing escort service and fire support.

3. Crew Size

The system as conceived carries two rated pilots; one is given extra gunnery functions.

4. Armament

Because this is a gunship, various configurations of armament are available, including: a TAT-102A subsystem (housed in a movable turret beneath the nose) and a 40mm grenade launcher.

External weapons, such as the four 19-tube launchers for 2.75-inch rockets, are attached to the stub wings.

5. Visibility

Visibility of fuselage positions behind or below the pilot is extremely limited. Because the engine is contained within a metal housing, neither the pilot nor gunner can view this area.

TABLE 3

UH-1 Caution Panel

ENG OIL PRESS	AUX FUEL LOW
ENGINE ICING	XMSN OIL PRESS
ENGINE ICE DETECT	XMSN OIL HOT
SPARE	HYD PRESSURE
LEFT FUEL BOOST	SPARE
RIGHT FUEL BOOST	INST INVERTER
ENG FUEL PUMP	DC GENERATOR
20 MINUTE FUEL	EXTERNAL POWER
FUEL FILTER	CHIP DETECTOR
SPARE	SPARE

6. Audio-Warning Devices

One audio-warning device is available in the AH-1G; this signal is a varying oscillating frequency which begins low and builds to a high pitch. It remains on for a 0.85-second interval, then off for 1.25 seconds, then on again. It is activated when rotor rpm is at 295 ± 5 or below, or the engine rpm is 6000 ± 100 or below, or both.

7. Special Problems

Because this aircraft is the newest, fastest, and one of the most maneuverable helicopters in operational service, and because it is used as a gunship, there may be a tendency of pilots to use these characteristics of the aircraft excessively. Thus, blade stall or other similar problems assume a greater degree of importance than for other slower, less maneuverable aircraft.

Because the engine for this aircraft can generate more power than the transmission is rated to handle, overtorquing can occur. Moreover, visibility of the fuselage and engine are limited, which makes detection of engine or fuselage fires extremely difficult. There currently are no warnings or sensors for either type of fire.

The role of this aircraft as a gunship may impose a different set of desired warnings upon the aircraft than for others. For example, it may be desirable to present warnings about the armament status, such as whether the ammunition is low or the wing stores are on fire.

Table 4 presents the AH-1G caution panel, and Figures 3, 4, and 5 are photographs of the AH-1G vehicle, pilot's instrument panel, and gunner's instrument panel, respectively.

D. CH-47 (CHINOOK) GENERAL DESCRIPTION

The CH-47 (Chinook) is a twin-engine cargo helicopter which has two 3-bladed main rotors. Each engine is a Lycoming T-55 series shaft-turbine mounted on the sides of the aft rotor pylon. The power of the engines is transmitted to the fore and aft rotor by means of a series of transmissions. The power from each engine is first transmitted to a 90-degree transmission which changes the direction of the power 90 degrees and transmits it to the combining transmission. The function of the combining transmission is to transmit power to the fore and aft rotor transmissions so that the rotor blades stay synchronized to avoid striking each other. The fore and aft transmissions transmit their power directly to the rotor shafts. The fuselage of the aircraft is cigar shaped, with rotor pylons at each end. The cockpit permits side-by-side

TABLE 4

AH-1G Caution Panel

Pilot's Panel

ENGINE OIL PRESS	XMSN OIL PRESS
ENGINE AIR	XMSN OIL HOT
ENG OIL BYPASS	HYD PRESS 1
FWD FUEL BOOST	HYD PRESS 2
AFT FUEL BOOST	INST INVERTER
ENG FUEL PUMP	DC GENERATOR
10% FUEL	EXTERNAL POWER
FUEL FILTER	CHIP DETECTOR
GOV EMER	IFF
XMSN OIL BYPASS	

Gunner's Panel

ENGINE OIL PRESS	XMSN OIL PRESS
ENGINE AIR	XMSN OIL HOT
ENG FUEL PUMP	CHIP DETECTOR
10% FUEL	HYD PRESS NO. 1
FUEL FILTER	HYD PRESS NO. 2
GOV EMER	INST INVERTER
DC GENERATOR	EXTERNAL POWER

seating of the pilot and copilot. The cargo ramp is located beneath the aft rotor pylon. The designed gross weight of the CH-47A and CH-47B is 28, 550 pounds and 33, 000 pounds, respectively. The overall length of the aircraft is 51 feet, and rotor diameter is 59 feet.

1. Performance Characteristics

The CH-47 has a maximum speed of 135 miles per hour and a cruise speed of 110 miles per hour. The fuel capacity is 4000 pounds of JP-4 fuel, and the maximum normal range is approximately 250 miles. The service ceiling is 11, 900 feet at 28, 550 pounds of gross weight and 9200 feet at 33, 000 pounds of gross weight.

2. Purpose

The CH-47 is primarily used as a cargo vehicle, although there are armed versions which are used as gunships. In its roll of carrying cargo, it is used primarily for carrying troops, supplies, and jeeps, and for medical evacuation. It can carry a platoon of 44 combat-equipped troops.

3. Crew Size

The crew consists of the pilot, copilot, crew chief, and a gunner/observer.

4. Armament

Inits cargo configuration, it may carry two 7.62mm machine guns The armed versions may be armed with a variety of machine guns, rockets, and artillery.

5. Visibility

The pilot and copilot have visibility forward, and downward, and to the side. They can not see any part of the fuselage aft of the cockpit Portholes are located on the sides of the fuselage. In the event of suspected fuselage or engine fire, the doors on the sides of the fuselage are opened to permit the crew chief to observe the fuselage.

6. Audio-Warning Devices

A crew alarm bell is present in the cargo hold aft of the cockpit. This alarm bell is used to alert troops for parachute drops, emergencies, and landings. It is manually actuated by the pilot or copilot.

7. Special Problems

The taxiing of this vehicle is a very special problem. The controls must be centered within limits or else the droop stops may be knocked out and possibly cause severe blade damage to the fuselage and, subsequently, to the other rotor blades during desynchronization. Droop stops must be checked prior to shutting down the engines, because the stops have been known to be lost during flight without the pilots knowledge.

Because of the high ambient noise level and the distance from the pilot, engine failures often are difficult to detect until well after they have occurred.

The tremendous power of the engines and the relatively large size of the fuselage often have resulted in a tendency of pilots to overload their aircraft under combat conditions.

Because the power of the engines is more than the transmission is rated to handle, overtorquing can occur. Unless the pilot is watching for this problem, he may not know it. If overtorquing occurs, special maintenance is required.

This vehicle has five transmissions; however, the pilot has only one indicator for transmission oil temperature and one indicator for transmission oil pressure. A selector switch for each parameter must be used to determine the specific transmission in which a problem exists.

There is currently no normal warning that a single SAS system has failed, unless the emergency SAS release switch has been used or a hydraulic servo failure also has occurred.

Table 5 presents the CH-47 caution panel, and Figures 6 and 7 show the CH-47 vehicle and instrument panel, respectively.

E. CH-54 (SKYCRANE) GENERAL DESCRIPTION

The CH-54 is a flying-crane helicopter capable of performing heavy-lift missions. It has two Pratt-and-Whitney gas turbine engines, each rated at 4050 shaft-horsepower. Its overall length is 88.5 feet, and the main rotor diameter is 72 feet. The empty gross weight of the vehicle is 17,240 pounds, while the normal maximum gross weight is 38,000 pounds, with an alternate gross weight of 42,000 pounds.

TABLE 5

CH-47 Caution Panel

Master Caution Panel	
TRANS OIL HOT	TRANS OIL PRESS
OIL LOW NO. 1 ENG	OIL LOW NO. 2 ENG
L FUEL PRESS	R FUEL PRESS
WHEEL DE-PHASED	--
NO. 1 HYD BOOST OFF	NO. 2 HYD BOOST OFF
--	PARK BRAKE ON
NO. 1 RECT OFF	NO. 2 RECT OFF
NO. 1 GEN OFF	NO. 2 GEN OFF
AC EXT PWR ON	DC EXT PWR ON
L FUEL LOW	R FUEL LOW
HEATER HOT	CARGO HOOK OPEN
NO. 1 SAS OFF	NO. 2 SAS OFF
Auxiliary Caution Panel	
L ENG CHIP DET	R ENG CHIP DET
XMSN CHIP DET	--
--	--
--	--

1. Performance Characteristics

The maximum level speed of the CH-54 is 117 miles per hour, and maximum cruise speed is 109 miles per hour. The maximum fuel capacity of 904 gallons is carried in two tanks. The range of this aircraft is very short (normal combat radius is less than 95 miles). The vehicle has a hovering ceiling of 9700 feet (IGE) or 4700 feet (OGE), and the maximum service ceiling of the aircraft is 10, 500 feet.

2. Purposes

This vehicle was designed primarily for the purposes of hauling heavy, large cargos, aircraft retrieval, construction work, moving heavy equipment, hauling troops in 68-seat troop vans, and medical evacuation.

3. Crew Size

The crew is comprised of a pilot, copilot, a third pilot, and the crew chief. The third pilot sits in a rearward-facing seat and usually flies the aircraft during loading or unloading cargo.

4. Armament

This aircraft is not armed.

5. Visibility

The crew has excellent visibility of the underside of the fuselage and the tail rotor section. Perhaps the only areas of the aircraft that can not be seen by the crew are the top of the fuselage, the main rotor, and the engines.

6. Audio-Warning Devices

There are no audio-warning devices currently installed in this aircraft.

7. Special Problems

Some instructor pilots in this aircraft indicate that due to high noise levels, it is possible to have an engine shutdown without some pilots being aware of what has happened. This problem is only critical at high gross weights because the aircraft has a single-engine hover capability for gross weights up to 38, 000 pounds.

It is possible for automatic engine shutdown to occur, because of differences in engine torque. This feature presumably is designed into this aircraft to protect the transmission from being overtorqued. It is possible to overtorque the transmission by applying too much power.

Currently, there is no engine fire extinguisher system aboard the aircraft.

Only the front pilot has a good indication of the amount of control authority remaining to the aft pilot when the aft pilot is flying the aircraft. The problem of transfer of control of the aircraft is unique to this vehicle.

The single-point hoist system is the key system in this aircraft. The hydraulically operated hoist is strong enough to raise or lower loads up to 15, 000 pounds (20, 000 pounds. static).

In this aircraft, the failure of both main hydraulic systems affects the operation of the flight control system and main rotor blades and is usually fatal. The first stage hydraulic system is driven by the No. 1 engine; the second stage hydraulic system is driven by the main rotor system.

Table 6 presents the CH-54 caution panel, and Figures 8 and 9 show the CH-54 vehicle and instrument panel, respectively.

F. OV-1 (MOHAWK) GENERAL DESCRIPTION

The OV-1 is a fixed-wing high-performance two-seat observation and reconnaissance aircraft. It has two Lycoming 1150-horsepower turbo-prop engines, each driving a three-blade reversible-pitch propeller. It has a wingspan of 42 feet and an overall length of 41 feet. The normal gross weight of the vehicle varies from 12.672 pounds to 13, 650 pounds, depending on the aircraft model and equipment; the normal empty weight may be as low as 10, 000 pounds. The aircraft has a hydraulically operated retractable tricycle landing gear.

1. Performance Characteristics

The normal maximum cruising speed of the OV-1 (which has a maximum speed of 308 miles per hour) varies from 275 to 304 miles per hour. The service ceiling of the aircraft is 30, 000 feet (although most missions in Viet Nam are conducted at altitudes between 1000 feet and 8000 feet of altitude). The single-engine service ceiling is 13, 625 feet. Its normal fuel capacity is 297 gallons in the fuselage and 300 gallons in drop tanks beneath the wings. The maximum range with external tanks is from 1230 to 1410 miles.

TABLE 6

CH-54 Caution and Advisory Panel

Caution Panel		
NO. 1 GENERATOR	CHIP DETECTOR	NO. 2 GENERATOR
NO. 1 RECTIFIER	TRANS OIL PRESS	NO. 2 RECTIFIER
NO. 1 FUEL PRESS	TRANS OIL HOT	NO. 2 FUEL PRESS
NO. 1 ENG FUEL BYPASS	INT TRANS OIL PRESS	NO. 2 ENG FUEL BYPASS
FWD FUEL LOW	AUX FUEL PRESS	AFT FUEL LOW
1ST STAGE SERVO	AUX SERVO PRESS	2ND STAGE SERVO
NO. 1 ENG ANTI-ICE ON	HEATER HOT	NO. 2 ENG ANTI-ICE ON
COPILOT PITOT HEAT	HOIST OIL PRESS	PILOT PITOT HEAT
COPILOT TURN & SLIP	HOIST OIL HOT	PILOT TURN & SLIP
---	ROTOR BRAKE PRESS	LDG GEAR KNEELED
Advisory Panel		
NO. 1 ENG STARGER ON	APP ON	NO. 2 ENG STARTER ON
NO. 1 ENG ANTI-ICE ON	APP HYD PRESS LOW	NO. 2 ENG ANTI-ICE ON
PARKING BRAKE ON	EXT PWR CONNECTED	ROTOR BRAKE ON
HOOK UNLOCKED	FUEL TEMP LOW	AUTO HOOK RELEASE

2. Purposes

The OV-1 is primarily used for observation, reconnaissance, and aerial photography. It carries side-looking radar (SLAR) tied in with ground equipment for real-time readout and airborne processing equipment (which provides the observer with photographs only seconds after the film has been exposed) Some aircraft carry flares for night reconnaissance, while others are armed for limited fire suppression.

3. Crew Size

The crew consists of the pilot and non-rated observer/electronic equipment operator. The crew is seated side by side on Martin-Baker ejection seats.

4. Armament

Normally, most OV-1 aircraft are unarmed. However, some versions have been fitted with external pods for machine guns and rockets.

5. Visibility

The pilot and observer have relatively good visibility of the nose and wing areas of the aircraft, but visibility of the fuselage and tail section is very poor. Because of the restricted visibility and the location of the main fuel cells in the fuselage, pilots report that it is difficult to detect fuselage fires.

6. Audio-Warning Devices

There are no audio-warning devices, such as a stall warning or gear-up device. The electronic countermeasures equipment sometimes carried aboard the aircraft has auditory information display (such as a "rattlesnake" buzzing) to indicate a missile has been fired at the aircraft.

7. Special Problems

Because fuselage fire is difficult to detect, pilots have indicated a general desire for sensors in this area.

Unlike multi-engine helicopters (such as the CH-47 or CH-54), pilots of the OV-1 report no difficulty in sensing that an engine failure has occurred. In this respect, they are able to see and hear the engines.

Pilots have, however, reported inadvertent propeller pitch reversal in flight.

The location of the caution panel or fault warning panel is in front of the throttle quadrant and parts of it are blocked from view when the throttles are advanced full forward. This could be especially critical during takeoff or any other time that full or nearly maximum power is applied.

Currently, there is a warning light in the cockpit to warn pilots of failure to lower the landing gear. This gear warning is actuated by the flap setting (15 degrees or more) and airspeed; however, it does not occur if the flaps are less that 15 degrees, such as in a no-flap landing. Gear-up accidents still occur even with the warning light.

There is currently no auditory indication of stall. Pilots have suggested looking into this problem because short field landings using minimum airspeed and maximum flap settings must be made in Viet Nam.

Table 7 presents the OV-1 caution panel, and Figures 10 and 11 show the OV-1 vehicle and instrument panel, respectively.

TABLE 7

OV-1 Caution Panel

NO. 1 FUEL PRESS	NO. 2 FUEL PRESS	INSTR PWR
NO. 1 GEN	NO. 2 GEN	FUEL LOW LEVEL
NO. 1 FUEL EMERG	NO. 2 FUEL EMERG	FUEL STRAINER
L DROP TANK	R DROP TANK	FUEL PUMPS
SPARE	SPARE	ENG ICE
AFCS	SPARE	SPARE

APPENDIX B

INFORMATION REQUIREMENTS ANALYSIS

TABLE 10

Analysis of UH-1 Emergency Tasks

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine failure	N_1 tachometer N_2 tachometer EPR EGT Fuel flow	Pilot sees aircraft start to descend	Pilot feels aircraft start to descend Pilot feels engine vibration stop	Pilot hears engine noise stop	10 to 15	S_1: engine instruments S_2: aircraft descends S_3: engine noise S_4: engine vibration S_5: engine failure	R_1: try restart R_2: land immediately	A	S_1, S_2, S_3, S_4 — S_5 — R_1, R_2	
Tail rotor failure	None	Pilot will see loss of directional control	Pilot will feel tail rotor fail and will notice loss of directional control	Pilot may hear tail rotor fail	0 to 5	S_1: loss of directional control S_2: tail rotor failure	R_1: maintain control of vehicle autorotate; land immediately	B	S_1 — S_2 — R_1	
Engine fire	Fire warning light	Evidence of smoke and fire usually can be seen	None	Pilot may hear and smell fire	0 to 5	S_1: fire warning light S_2: sees smoke S_3: engine fire	R_1: land immediately	A	S_1, S_2 — S_3 — R_1	
Fuselage fire	None	Evidence of smoke and fire usually can be seen	None	Fire and smoke can often be heard and smelled	0 to 5	S_1: pilot sees fuselage fire S_2:	R_1: land immediately	A	S_1 — S_2 — R_1	
Electrical fire	Load meter	Sparks and arcing of electrical wires may often be seen	None	Arcing of electrical wires may be heard Burning insulation can be smelled	0 to 5	S_1: smells smoke S_2: sees fire S_3: electrical fire	R_1: isolate source of fire by removing electrical power, then continue R_2: land immediately	B	S_1, S_2 — S_3 — R_1, R_2	
Fuel boost pump failure	MASTER CAUTION LIGHT Fuel pressure indicator Fuel pressure light	None	None, unless engine performance is affected	None, unless engine performance is affected	0 to 20	S_1: fuel pressure light S_2: engine performance S_3: fuel boost pump failure	R_1: above 4600 feet, descend R_2: below 4600 feet, no problem	B	S_1, S_2 — S_3 — R_1, R_2	

A. Requires rapid response which takes precedence over all other activities.
B. Requires quick attention, but there is time for double checking and diagnosis.
C. Pilot attends to when time permits.
D. Requires knowledge of but no response.

TABLE 10 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine fuel control (low)	MASTER CAUTION LIGHT; Fuel pressure warning light	None	May feel loss of power	May hear loss of power	0 to 120	S_1: fuel pressure warning light; S_2: loss of power; S_3: engine fuel control	R_1: below 4600 feet, no problem; R_2: above 4600 feet, must descend	B	$S_1, S_2 > S_3 < R_1, R_2$	
Engine fuel control (high)	MASTER CAUTION LIGHT; Fuel pressure warning light	None		May hear surge of power	--	S_1: fuel pressure warning light; S_2: surge in power; S_3: engine fuel control	R_1: below 4600 feet, no problem; R_2: above 4600 feet, must descend	B	$S_1, S_2 > S_3 < R_1, R_2$	
Electrical power system	All electrical instruments; MASTER CAUTION LIGHT; Generator light (d-c)	None	None		0 to 5	S_1: generator warning light (d-c); S_2: circuit breaker; S_3: electrical power system	R_1: try to isolate by checking fuses and circuit breakers; if unable to isolate, land	B	$S_1, S_2 > S_3 — R_1$	
Inverter (a-c)	MASTER CAUTION LIGHT; Attitude indicator (at side); Instrument inverter light	None	None		0 to 5	S_1: instruct inverter; S_2: circuit breaker; S_3: inverter (a-c)	R_1: check fuses and circuit breakers; R_2: return to base	B	$S_1, S_2 > S_3 < R_1, R_2$	
Hydraulic power system	MASTER CAUTION LIGHT; Hydraulic pressure warning light	None	Controls will become stiff	None	0 to 5	S_1: hydraulic power system pressure warning light; S_2: hydraulic power failure (No. 1, No. 2, or both)	R_1: maintain control short system; continue to nearest base	C	$S_1 — S_2 — R_1$	Failure of both hydraulic systems is not critical except on the "C" model of the UH-1. A double failure on the "C" model can be fatal.
Flight controls		None	Pilot will feel loss of cyclic control	None	--	S_1: control feel; S_2: flight control failure	R_1: attempt to maintain control; land immediately	A	$S_1 — S_2 — R_1$	

*A Requires rapid response which takes precedence over all other activities.
B Requires quick attention, but there is time for double checking and diagnosis.
C Pilot attends to when time permits.
D Requires knowledge of but no response.

TABLE 10 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Perceptual Requirements: Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Rotor rpm low	MASTER CAUTION LIGHT Rotor rpm indicator Low rotor speed warning light	Aircraft may begin to descend	Controls get sloppy Pilot will feel loss of altitude	Audio warning Rotor noise will sound low	--	S_1: audio warning S_2: rotor rpm indicator S_3: rotor rpm warning light S_4: aircraft descends S_5: rotor rpm low	R_1: down on collective R_2: forward on cyclic R_3: increase power	A	S_1, S_2, S_3, S_4 — S_5 — R_1, R_2, R_3	
Rotor rpm high	MASTER CAUTION LIGHT Rotor rpm indicator Rotor rpm warning light	Aircraft will tend to ascend	Abnormal vibration may occur	Rotor noise may sound high	0 to 5	S_1: rotor rpm indicator S_2: rotor rpm warning light S_3: rotor sound S_4: rotor rpm high	R_1: increase collective R_2: attitude on cyclic R_3: reduce power	A	S_1, S_2, S_3 — S_4 — R_1, R_2, R_3	
Chip detector	MASTER CAUTION LIGHT Chip detector light	None	None	None, unless engine affected	0 to 5	S_1: chip detector warning light S_2: chip in transmission or engine	R_1: land immediately	B	S_1 — S_2 — R_1	
Low engine oil	MASTER CAUTION LIGHT Oil pressure gauge Engine oil pressure light	None	None	None	0 to 5	S_1: engine oil pressure warning light S_2: engine oil pressure indicator S_3: oil pressure low	R_1: check engine oil temperature; abort mission; continue mission	B	S_1, S_2 — S_3 — R_1	
Engine icing	MASTER CAUTION LIGHT Engine instruments Engine ice detector light	Crew can usually see evidence of icing	May feel power loss	May hear power loss	0 to 5	S_1: engine ice detector light S_2: engine icing	R_1: descend	A	S_1 — S_2 — R_1	
Low fuel quantity	MASTER CAUTION LIGHT Fuel quantity gauge Fuel pressure Twenty-minute fuel light	None	None	None	0 to 5	S_1: twenty-minute fuel warning light S_2: fuel quantity S_3: fuel low	R_1: land at nearest friendly base	B	S_1, S_2 — S_3 — R_1	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 10 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Auxiliary fuel tank empty	MASTER CAUTION LIGHT Fuel quantity gauge Fuel pressure gauge Auxiliary fuel low light	None	None	None	0 to 5	S_1: auxiliary fuel low light S_2: fuel quantity indicator S_3: auxiliary fuel tank low	R_1: land at nearest friendly base	B	$S_1, S_2 > S_3 — R_1$	
Low transmission oil pressure	MASTER CAUTION LIGHT Transmission oil temperature gauge Transmission oil hot light	None	None	None	0 to 5	S_1: transmission oil pressure warning light S_2: transmission oil pressure indicator S_3: transmission oil pressure low	R_1: land as soon as possible	B	$S_1, S_2 > S_3 — R_1$	
High transmission oil temperature	MASTER CAUTION LIGHT Transmission oil pressure gauge Transmission oil pressure light				0 to 5	S_1: transmission oil temperature high warning light S_2: transmission oil temperature gauge S_3: transmission oil temperature high	R_1: land as soon as possible	B	$S_1, S_2 > S_3 — R_1$	
Fuel filter bypass	MASTER CAUTION LIGHT Fuel flow Fuel filter inoperative light	None	None	None	0 to 5	S_1: fuel filter inoperative warning light S_2: fuel flow S_3: fuel filter clogged	R_1: check engine performance	C	$S_1, S_2 > S_3 — R_1$	
EGT high (low)	Engine instruments EGT	None	None, unless engine performance is affected	None, unless engine performance is affected	0 to 60	S_1: EGT indicator S_2: EGT high	R_1: reduce power R_2: monitor engine performance	B	$S_1 — S_2 < R_1, R_2$	

*A. Requires rapid response which takes precedence over all other activities.
B. Requires quick attention, but there is time for double checking and diagnosis.
C. Pilot attends to when time permits.
D. Requires knowledge of but no response.

TABLE 11

Analysis of AH-1G Emergency Tasks

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine failure	Engine instruments: N_1 tachometer, N_2 tachometer, EPR, EGT, Fuel flow, Torquemeter; Rotor rpm	Aircraft will not be able to maintain altitude	Pilot will feel power loss	Pilot will hear power loss	0 to 10	S_1: torque S_2: N_1 rpm S_3: engine noise S_4: aircraft descends S_5: engine failure	R_1: try a restart R_2: land immediately	A	S_1, S_2, S_3, S_4 — S_5 — R_1, R_2	
Loss of tail rotor	Flight director	Difficulty of directional control	Pilot will feel tail rotor fail and will notice loss of directional control	Pilot may possibly hear tail rotor fail	0 to 5	S_1: loss of directional control S_2: loss of tail rotor	R_1: increase speed R_2: land immediately	A	S_1 — S_2 — R_1, R_2	Problem is rather obvious; perhaps no need for an additional alerting device.
Loss of tail pylon	Flight director	None	Pilot will feel tail pylon loss	Pilot will hear tail pylon loss	0 to 5	S_1: kinesthetic cues S_2: loss of tail pylon	R_1: increase speed to maintain direction R_2: land immediately	A	S_1 — S_2 — R_1, R_2	
Hot start	EGT; Gas producer tachometer; N_1 tachometer	Fireguard will see fire in tail pipe	None	Crew can smell unburned fuel; may hear backfire	0 to 5	S_1: EGT high S_2: sees fire S_3: hot start	R_1: shutdown; wait 30 seconds R_2: extinguish fire	A	S_1, S_2 — S_3 — R_1, R_2	This emergency probably could be covered by the warning for engine fire.
Engine fire	Fuel pressure; EGT; Engine oil pressure		Pilot may feel power loss	Pilot may hear power loss; Pilot may smell burning	0 to 60	S_1: EGT high S_2: pilot may see S_3: engine fire	R_1: land immediately; shut down engine; abandon aircraft	A	S_1, S_2 — S_3 — R_1	A specific warning is highly desirable.
Fuselage fire	None	May see fire	None	Crew may smell fire	0 to 60	S_1: sees fire in fuselage	R_1: land immediately; abandon vehicle	A	S_1 — R_1	Due to danger of fuel cells, short response time, and difficulty to control, a voice warning for this emergency is desirable.
Electrical fire	Load meter	Crew may see sparks and arcing of electrical current	None	Crew may smell burning insulation	0 to 10	S_1: smells S_2: sees indication of electrical failure S_3: electrical fire	R_1: isolate cause of fire by pulling circuit breakers R_2: land immediately	B	S_1, S_2 — S_3 — R_1, R_2	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 11 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Wing stores fire	None	Crew may see smoke coming from stores	None	Will hear if explosions occur	0 to 10	S_1: sees fire	R_1: increase speed and try to blow out, jettison stores	A	S_1 — R_1	
Fuel boost pump	MASTER CAUTION LIGHT Fuel pressure gauge Forward or aft fuel boost warning light	None	None, unless above 4600 feet; above 4600 feet, engine will starve	None	0 to 10	S_1: fuel boost warning light S_2: engine failure symptoms S_3: fuel boost pump (forward or aft)	R_1: above 4600 feet, descend R_2: below 4600 feet, continue flight	C	$S_1, S_2 > S_3 < R_1, R_2$	
Engine fuel control (low)	Fuel pressure gauge	None	Pilot will feel power loss	Pilot will hear power loss	0 to 30	S_1: fuel pressure gauge S_2: loss of power S_3: engine fuel control (low) failure	R_1: above 4600 feet, descend R_2: below 4600 feet, continue flight	B	$S_1, S_2 > S_3 < R_1, R_2$	
Engine fuel control (high)	Fuel pressure gauge		Pilot will feel power surge	Pilot will hear surge in power	0 to 30	S_1: fuel pressure gauge S_2: surge in engine S_3: engine fuel control (high) failure	R_1: above 4600 feet, descend R_2: below 4600 feet, continue flight	B	$S_1, S_2 > S_3 < R_1, R_2$	
Electrical power system	MASTER CAUTION LIGHT Generator light (d-c) Electrical instruments Generator warning light (d-c)	None	None	None	0 to 5	S_1: generator warning light (d-c) S_2: electrical instruments S_3: electrical power system failure	R_1: check fuses and circuit breakers R_2: land if unable to fix	B	$S_1, S_2 > S_3 < R_1, R_2$	
Inverter (a-c)	MASTER CAUTION LIGHT Instrument inverter warning light	None; loses equipment using a-c current	None	None	0 to 5	S_1: instrument inverter warning light S_2: loss of electrical equipment S_3: inverter failure (a-c)	R_1: check switches and check fuses R_2: abort mission, if necessary	B	$S_1, S_2 > S_3 < R_1, R_2$	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 11 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Hydraulic system, No. 1 or No. 2 (single failure)	MASTER CAUTION LIGHT Hydraulic pressure indicator No. 1 or No. 2 hydraulic pressure warning lights	None	Pilot will feel through control	None	0 to 5	S_1: hydraulic pressure No. 1 or No. 2 warning light S_2: control feel S_3: hydraulic failure No. 1 or No. 2 system	R_1: land when opportunity occurs	C	$S_1, S_2 \to S_3 \to R_1$	
Hydraulic system, No. 1 and No. 2 (double failure)	MASTER CAUTION LIGHT Hydraulic pressure indicator No. 1 and No. 2 hydraulic pressure warning lights	None	Pilot will feel loss of system through stiffness of controls	None	0 to 5	S_1: hydraulic pressure No. 1 and No. 2 warning light S_2: control feel S_3: hydraulic failure No. 1 and No. 2 system	R_f: land at nearest base	C	$S_1, S_2 \to S_3 \to R_1$	
Flight control system	None	None	Pilot will feel	None	0 to 5	S_1: control feel S_2: control failure	R_1: trys to autorotate	A	$S_1 \to S_2 \to R_1$	
Rotor rpm (low)	MASTER CAUTION LIGHT Rotor rpm indicator Warning light (rpm)	May lose altitude	Controls will begin to feel sloppy Directional control difficult	Audio warning Rotor blade noise will indicate condition	0 to 5	S_1: audio warning signal S_2: rpm warning light S_3: rotor sound S_4: aircraft descends S_5: rotor rpm low	R_1: down on collective R_2: forward on cyclic R_3: increase rpm	A	$S_1, S_2, S_3, S_4 \to S_5 \to R_1, R_2, R_3$	
Rotor rpm (high)	MASTER CAUTION LIGHT Rotor rpm indicator Warning light (rpm)	May increase altitude	Aircraft may vibrate	Rotor blade noise will indicate condition	0 to 5	S_1: rpm warning light S_2: rpm indicator S_3: rotor sound S_4: aircraft performance S_5: rotor rpm high	R_1: up on collective R_2: aft on cyclic R_3: decrease rpm	A	$S_1, S_2, S_3, S_4 \to S_5 \to R_1, R_2, R_3$	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 11 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Chip detector	MASTER CAUTION LIGHT Individual chip detector indicators Chip detector warning light	None	None	None	0 to 5	S_1: chip detector warning light S_2: transmission or tail rotor chips	R_1: check to see where chip is located and land	A	S_1 — S_2 — R_1	
Low engine oil pressure	MASTER CAUTION LIGHT Engine oil pressure gauge Engine oil pressure warning light	None	None	None	0 to 5	S_1: engine oil pressure warning light S_2: engine oil pressure indicator S_3: low engine oil pressure	R_1: check engine oil temperature (if temperature increased, land immediately) R_2: continue	B	$S_1, S_2 > S_3 < R_1, R_2$	
Engine air	MASTER CAUTION LIGHT Engine air warning light	None	Engine may not produce correct power	May hear loss of engine power	0 to 5	S_1: engine air warning light S_2: negative engine air pressure	R_1: lower noise of aircraft; try to clear out	B	S_1 — S_2 — R_1	
Engine oil bypass	MASTER CAUTION LIGHT Engine oil pressure gauge Engine oil bypass warning light	None	None	None	0 to 5	S_1: engine oil bypass warning light S_2: Engine oil warning bypass	R_1: keep checking engine oil pressure	C	S_1 — S_2 — R_1	
Low fuel quantity	MASTER CAUTION LIGHT Fuel quantity gauge Fuel pressure gauge Ten percent fuel warning light	None	None	None	0 to 5	S_1: ten percent fuel warning light S_2: fuel quantity gauge S_3: fuel low	R_1: decide where to land; decide whether to continue mission	B	$S_1, S_2 > S_3$ — R_1	
Fuel filter obstructed	MASTER CAUTION LIGHT Fuel flow Fuel filter warning light	None	None; unless engine performance is affected	None	0 to 5	S_1: fuel filter warning light S_2: fuel filter clogged	R_1: continue mission R_2: land at nearest base	C	S_1 — $S_2 < R_1, R_2$	

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C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 11 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Transmission oil bypassing oil cooler	MASTER CAUTION LIGHT Transmission oil temperature Transmission oil bypass warning light	None	None	None	0 to 5	S_1: transmission oil bypass warning light S_2: transmission oil bypassing oil cooler	R_1: check transmission oil pressure and temperature; if normal, continue mission; if abnormal, land immediately	C	S_1 — S_2 — R_1	
Low transmission oil pressure	MASTER CAUTION LIGHT Transmission oil pressure gauge Low transmission oil pressure warning light	None	None	None	0 to 5	S_1: low transmission oil pressure warning light S_2: transmission oil pressure indicator S_3: transmission oil temperature indicator S_4: transmission oil pressure low	R_1: land immediately if changes in pressure and temperature have occurred	B	S_1, S_2, S_3 — S_4 — R_1	Will normally check transmission oil temperature.
High transmission oil temperature (above red line)	MASTER CAUTION LIGHT Transmission oil temperature gauge High transmission oil temperature warning light	None	None	None	0 to 5	S_1: high transmission oil temperature warning light S_2: transmission oil pressure indicator S_3: transmission oil temperature high	R_1: land immediately if changes in temperature and pressure	B	S_1, S_2 — S_3 — R_1	Will normally check transmission oil pressure.
IFF system inoperative	MASTER CAUTION LIGHT IFF warning light	None	None	None	0 to 5	S_1: IFF warning light S_2: IFF inoperative	R_1: none	D	S_1 — S_2 — R_1	
EGT high (low)	EGT indicator	None	None	None	0 to 60	S_1: EGT indicator S_2: EGT high	R_1: reduce power	B	S_1 — S_2 — R_1	

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D: Requires knowledge of but no response.

TABLE 11 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine rpm low	Warning light (rpm) Indicator (rpm)	Aircraft may descend	Pilot will feel lower engine vibration and will feel if aircraft descends	Audio warning (rpm) Pilot may hear lower engine rpm	0 to 5	S_1: engine rpm indicator S_2: engine rpm low	R_1: increase power R_2: prepare for landing	B	$S_1 — S_2 < R_1, R_2$	

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C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 12

Analysis of CH-47 Emergency Tasks

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine failure (either left or right)	Engine instruments Rotor rpm	May see loss of altitude	Possibly may feel loss of power (feels through body weight)	Possibly may hear engine quit	0 to 30	S_1: torque S_2: N_1 rpm S_3: altitude loss S_4: engine noise S_5: kinesthetic cues S_6: engine failure	R_1: shut down affected engine R_2: keep up good engine R_3: try restart if engine failure not due to mechanical reasons R_4: land as soon as possible	A	$S_1, S_2, S_3, S_4, S_5 \rightarrow S_6 \rightarrow R_1, R_2, R_3, R_4$	A voice warning of an engine failure is highly desirable. It may also be desirable to give the components of an engine failure, such as EGT, rpm. Warning should tell which engine has failed; i.e., left or right.
Engine failure (both engines)	Engine instruments Rotor rpm	Will see aircraft lose altitude	Will feel loss of power Will feel aircraft descend	Will hear engines stop Will hear rotor rpm fall off	0 to 20	S_1: torque S_2: rotor rpm S_3: altitude loss S_4: kinesthetic cues S_5: engine noise S_6: engine failure	R_1: try restart if engine failure not due to mechanical reasons R_2: shut down engines if time permits R_3: prepare for emergency landing	A	$S_1, S_2, S_3, S_4, S_5 \rightarrow S_6 \rightarrow R_1, R_2, R_3$	Abundance of stimuli implies an additional alerting device may not be necessary.
Engine fire Left engine Right engine	Fire control handle light, left or right Engine instruments EGT EPR N_1 rpm N_2 rpm Fuel flow	May not be able to see fire due to location of engines (crew chief may examine by leaning out of aircraft)	None, unless engine performance is affected	None	0 to 30	S_1: fire control handle S_2: engine performance S_3: crew reports visual contact S_4: fire (left or right engine)	R_1: extinguish fire R_2: shut down affected engine R_3: land immediately	A	$S_1, S_2, S_3 \rightarrow S_4 \rightarrow R_1, R_2, R_3$	A voice warning for this emergency is highly desirable. The warning should tell which engine (left or right) is on fire so that the pilot knows which engine to shut down and on which to dump extinguishing agent.
Fuselage fire	None	May not see fire due to poor visibility of fuselage Crew chief may have to lean out to see	None	Possibly may smell burning material and fuel	0 to 300	S_1: visual detection S_2: fuselage fire	R_1: land immediately	A	$S_1 — S_2 — R_1$	Sensors are being considered for this emergency. It is dangerous because of the location of the fuel cells.

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D: Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Electrical fire	Circuit breakers	May see sparks and arcing of wires May see smoke	None	May smell burning insulation	0 to 300	S_1: circuit breakers S_2: smell S_3: smoke and sparks S_4: electrical fire	R_1: isolate cause of fire using circuit breakers R_2: land immediately	A	$S_1, S_2, S_3 > S_4 < R_1, R_2$	A warning for electrical fire may not be feasible, due to lack of sensors.
Engine chip detected (left or right)	MASTER CAUTION LIGHT Left or right engine chip detection light	None	None	None	0 to 30	S_1: engine chip warning light S_2: engine chip	R_1: shut down affected engine R_2: land immediately	B	$S_1 — S_2 < R_1, R_2$	Pilots complain of the frequency with which this light warning comes into view. Message should tell which of the two engines is faulty.
Transmission chip detected	MASTER CAUTION LIGHT Transmission chip detector light	None (pilot may check transmission oil pressure and temperature)	None	None	0 to 30	S_1: transmission chip detected S_2: transmission chip	R_1: land immediately	B	$S_1 — S_2 — R_1$	Pilots complain of the frequency with which this warning occurs.
Hydraulic system (single failure)	MASTER CAUTION LIGHT Hydraulic pressure indicator No. 1 or No. 2 hydraulic boost warning light	None	Pilot may feel disturbance through controls	None	0 to 30	S_1: hydraulic boost warning light S_2: hydraulic pressure indicator S_3: control feel S_4: hydraulic system failure (No. 1 or No. 2)	R_1: land immediately	B	$S_1, S_2 > S_3 — R_1$	A double hydraulic failure is normally fatal, due to loss of control. A single message about the hydraulic failure should be sufficient.
Hydraulic system failures (both systems)	MASTER CAUTION LIGHT Hydraulic pressure indicator No. 1 and No. 2 hydraulic boost warning light	Aircraft becomes uncontrollable and unstable	Controls will freeze and become impossible to move	None	0 to 5	S_1: hydraulic boost warning lights S_2: control feel S_3: lack of aircraft stability S_4: hydraulic pressure indicator S_5: failure of both hydraulic systems	R_1: attempt to maintain control R_2: try to start APU R_3: make emergency landing	A	$S_1, S_2, S_3, S_4 > S_5 < R_1, R_2, R_3$	This failure is normally fatal.

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D Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Utility hydraulic system	Utility hydraulic pressure indicator	None	None	None	0 to 300	S_1: utility hydraulic pressure indicator S_2: failure of utility hydraulic system	R_1: land at nearest airfield	C	S_1 — S_2 — R_1	
Stability augmentation system (SAS) (single or double failure)	None	Checks master caution panel to see that SAS has not been turned off	May feel "bump" in controls until other SAS takes over If both SAS go, control is erratic	None	0 to 600	S_1: control feel S_2: SAS failure (No. 1, No. 2, or both)	R_1: switch to good SAS R_2: turn off both SAS R_3: continue mission R_4: land at nearest airfield	C	S_1 — S_2 < R_1, R_2, R_3, R_4	This emergency is not considered to be serious. Correct visual warning occurs only if the SAS has been turned off.
Longitudinal cyclic trim failure	Circuit breakers (a-c) Circuit breakers (d-c)	None	Pilot will notice inability to trim aircraft due to ineffectiveness of cyclic trim switch	None	0 to 300	S_1: control feel S_2: longitudinal cyclic trim failure	R_1: turn off SAS R_2: continue mission R_3: land at nearest airfield	C	S_1 — S_2 < R_1, R_2, R_3	Not hazardous to flight.
Normal engine beep trim switch failure	Engine instruments Torque N_1 rpm N_2 rpm EPR	Pilot will see failure	Pilot will notice failure of engines to beep up or down to maintain engine torque balance	None	0 to 300	S_1: difficulty matching engine torque S_2: normal engine beep trim switch failure	R_1: use emergency engine trim switch to increase or decrease engine rpm	C	S_1 — S_2 — R_1	
Fuel booster pump (single)	Engine instruments EGT EPR Fuel flow N_1 rpm N_2 rpm Torque Fuel pressure Fuel quantity		None	None	0 to 30	S_1: engine performance S_2: fuel pressure S_3: fuel booster pump failure	R_1: descend below 6000 feet R_2: continue mission R_3: restart engines if failure occurs	B (above 6000 feet) C (below 6000 feet)	S_1, S_2 > S_3 < R_1, R_2, R_3	This failure becomes known only if both fuel pumps fail on tank (left or right).

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D: Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Fuel pressure drop	MASTER CAUTION LIGHT Engine instruments EPR EGT N_1 rpm N_2 rpm Fuel flow Fuel pressure Fuel quantity Left or right fuel pressure warning light	None	May feel engine begin to fail	None, unless engine performance is affected	0 to 30	S_1: fuel pressure warning light S_2: fuel pressure indicator S_3: fuel pressure emergency	R_1: land immediately	B	$S_1, S_2 > S_3 — R_1$	
Low oil quantity	MASTER CAUTION LIGHT Oil pressure indicator Low oil quantity, No 1 or No. 2 engine warning light	May examine oil temperature indicator	None	None	0 to 30	S_1: oil pressure warning light S_2: oil pressure indicator (left or right engine) S_3: low oil quantity (either left or right engine)	R_1: monitor engine performance R_2: shut down engine if required R_3: land at nearest airbase	B	$S_1, S_2 > S_3 < R_1, R_2, R_3$	
Transformer rectifier failure (single or both fail)	MASTER CAUTION LIGHT No. 1 or No. 2 rectifier off Loadmeter	Pilot may experience a diminishment in power in instruments	None	None	0 to 30	S_1: transformer rectifier warning light (No. 1 or No 2) S_2: instruments S_3: transformer rectifier failure (No. 1 or No 2)	R_1: turn off non-essential electrical equipment R_2: turn on emergency power R_3: try to isolate problem R_4: try to get power back R_5: land at nearest airbase	C	$S_1, S_2 > S_3 < R_1, R_2, R_3, R_4, R_5$	This failure is not extremely serious. Probably one warning would be sufficient, such as calling the pilots attention to the emergency panel

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D Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/ Response Relationship	Comments
Generator failure (a-c) (both)	MASTER CAUTION LIGHT Circuit breakers No. 1 and No. 2 generator warning lights	Loss or diminishment of electrical power	None	None	0 to 30	S_1: generator warning light S_2: loss of a-c current S_3: generator failure (a-c)	R_1: isolate problem R_2: switch to emergency power R_3: try to get power back R_4: land at nearest airbase	C	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3, R_4$	
Generator failure (a-c) (single)	MASTER CAUTION LIGHT Circuit breakers No. 1 or No. 2 generator warning lights	Loss or diminishment of electrical power	None	None	0 to 30	S_1: generator warning light S_2: circuit breakers S_3: generator failure (a-c)	R_1: isolate problem R_2: switch to emergency power R_3: try to get power back R_4: land at nearest airbase	C	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3, R_4$	
Fuel low	MASTER CAUTION LIGHT Fuel quantity Left or right fuel low warning light	None	None	None	0 to 30	S_1: fuel warning light S_2: fuel quantity S_3: fuel low	R_1: reduce fuel consumption R_2: look for emergency landing field if required R_3: land as soon as possible	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3$	
Wheel dephased	MASTER CAUTION LIGHT Wheel dephased caution light	If landing, directional control may be difficult	None, unless on ground Pilot will notice directional control difficulty on ground	None	0 to 30	S_1: warning light S_2: wheel dephased problem	R_1: land from hover	C	$S_1 — S_2 — R_1$	Critical only for landing and ground handling.
Cargo hook open	MASTER CAUTION LIGHT Cargo hook open light	None	None	None	0 to 30	S_1: warning light S_2: cargo hook open	R_1: close hook	D	$S_1 — S_2 — R_1$	

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D: Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Transmission oil pressure	MASTER CAUTION LIGHT Transmission oil Pressure indicator Pilot must use transmission oil pressure selector switch Transmission oil pressure warning light	None	None	None	0 to 30	S_1: warning light S_2: transmission oil pressure indicator S_3: transmission oil pressure low	R_1: land immediately	B	$S_1, S_2 > S_3 — R_1$	This warning is extremely important.
Transmission oil temperature	MASTER CAUTION LIGHT Transmission oil Temperature indicator Transmission oil temperature selector switch Transmission oil temperature light	None	None	None	0 to 30	S_1: warning light S_2: transmission oil temperature indicator S_3: transmission oil temperature high	R_1: land immediately	B	$S_1, S_2 > S_3 — R_1$	This is a very high priority failure.
Over torquing	Torquemeter	None	May feel if transmission is affected	May hear higher engine noise	--	S_1: torquemeter S_2: over-torquing	R_1: reduce torque	A	$S_1 — S_2 — R_1$	Definite need for warning.
Rotor speed low (below 220 rpm)	Rotor rpm	Pilot may notice aircraft beginning to descend	Controls will feel sloppy Directional control will become difficult	Pilot will hear lower rotor speed	--	S_1: rotor rpm indicator S_2: aircraft descends S_3: control feel S_4: auditory cues S_5: rotor speed low	R_1: increase engine torque R_2: adjust collective and cyclic to maintain control and bring up rpm	A	$S_1, S_2, S_3, S_4 > S_5 < R_1, R_2$	

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C. Pilot attends to when time permits.
D. Requires knowledge of but no response.

TABLE 12 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Rotor speed high (above 236 rpm)	Rotor rpm indicator		Pilot will feel high rotor rpm	Pilot may hear	--	S_1: rotor rpm indicator S_2: control feel S_3: auditory cues S_4: rotor speed high	R_1: use engine beep trim, cyclic control, and collective control to reduce rotor rpm	A	$S_1, S_2, S_3 > S_4$ — R_1	
Difference in torque between engines	Engine torquemeters N_1 rpm for both engines	None	None	None	--	S_1: engine torquemeters S_2: torque difference between engines	R_1: match torques	B	S_1 — S_2 — R_1	
N_1 rpm low (left or right engine)	N_1 rpm indicator (left or right engine)	None	Pilot may feel loss of power	Pilot may or may not hear loss of engine rpm	--	S_1: N_1 rpm indicator S_2: kinesthetic cues S_3: auditory cues S_4: N_1 rpm low (left or right engine)	R_1: check engine operation R_2: beep up engine R_3: if engine is bad, shut down	B	$S_1, S_2, S_3 > S_4 < R_1, R_2, R_3$	
EGT high (left or right engine)	EGT indicator engine torque N_1 and N_2 rpm		Pilot may notice loss of power		--	S_1: EGT indicator S_2: engine torque S_3: EGT high	R_1: reduce power on engine	B	$S_1, S_2 > S_3$ — R_1	
Controls not centered	None	Pilot can see controls	Pilot may feel bumping of droop stops after landing	Pilot may hear droop stops pounding if controls not centered	--	S_1: feels droop stop pounding S_2: hears droop stop pounding S_3: controls not centered	R_1: center controls	B	$S_1, S_2 > S_3$ — R_1	This problem can cause damage to fuselage if not attended to immediately.
Over gross weight	None	Aircraft may not rise or maintain altitude	Aircraft	None	--	S_1: aircraft performance S_2: over gross weight	R_1: remove excess weight	B	S_1 — S_2 — R_1	A serious problem in Viet Nam due to conditions of operation and size of aircraft.

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D: Requires knowledge of but no response.

TABLE 12 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
External power on (a-c)	MASTER CAUTION LIGHT External power on warning light (a-c)				0 to 30	S_1: warning light S_2: external power (a-c)	R_1: discon-nect power	C	S_1 — S_2 — R_1	Occurs on ground.
External power on (d-c)	MASTER CAUTION LIGHT External power on warning light (d-c)				0 to 30	S_1: warning light S_2: external power on (d-c)	R_1: discon-nect power	C	S_1 — S_2 — R_1	Occurs on ground.
Parking brake	MASTER CAUTION LIGHT Parking brake on	Parking brake handle	None	None	0 to 30	S_1: parking brake on S_2: parking brake locked	R_1: release brake	C	S_1 — S_2 — R_1	
Heater hot	MASTER CAUTION LIGHT Heater hot warning light				0 to 30	S_1: warning light S_2: heater hot	R_1: wait few minutes, try to re-start	D	S_1 — S_2 — R_1	
Fuel booster pump (both pumps on one tank)	MASTER CAUTION LIGHT Left or right fuel pressure light Engine instruments EGT EPR Fuel flow N_1 rpm N_2 rpm Torque Fuel pressure	None	None, unless engine per-formance is affected above 6000 feet None below 6000 feet	None below 6000 feet Above 6000 feet engine performance may be affected	0 to 30	S_1: warning light S_2: fuel pres-sure in-dicator S_3: engine perform-ance S_4: fuel booster pump	R_1: descend below 6000 feet R_2: open crossfeed switch; restart any en-gine that stopped due to pressure loss R_3: land at nearest airbase	B (above 6000 feet) C (below 6000 feet)	$S_1, S_2, S_3 > S_4 < R_1, R_2, R_3$	

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B Requires quick attention, but there is time for double checking and diagnosis.
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D Requires knowledge of but no response.

TABLE 13

Analysis of CH-54 Emergency Tasks

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine failure (left or right engine)	Engine instruments Transmission instruments Rotor rpm Torque	May see descent	May feel change in body forces Sense of descent Control feel loose	May hear unwinding of turbine	0 to 30	S_1 engine instruments S_2 torque S_3: rotor rpm S_4 body forces S_5: hears turbines unwinding S_6: engine failure (left or right engine)	R_1 restart R_2 shut down and land	L Engine A R Engine B	S_1, S_2, S_3, S_4, S_5 — S_6 — R_1, R_2	The amount of noise in the environment may mask auditory stimuli; and visual cues may not be noticed; therefore, time to detect may be too long. Voice-warning system should indicate which engine has failed.
Engine failure (both engines)	Engine instruments Transmission instruments Rotor rpm Torque	Will see aircraft begin to descend	Will feel decent Control feel loose	Engine noise will indicate that the turbines are unwinding	0 to 5	S_1 engine instruments S_2 torque S_3: rotor rpm S_4: sees aircraft descend S_5: body forces S_6. lack of engine noise S_7: failure of both engines	R_1: restart R_2: land R_3: jettison load	A	S_1, S_2, S_3, S_4, S_5, S_6 — S_7 — R_1, R_2, R_3	Voice warning for this emergency may not be necessary to alert pilot to this failure.
Engine fire	Fire warning light Engine instruments EGT EPR N_1 rpm N_2 rpm Fuel flow	May see smoke, explosion, or flame	If engine fails, then cues are same as for engine failure If engine continues, then no kinesthetic cues are given	May or may not hear timing explosions if they occur	0 to 30	S_1: fire warning light S_2 see smoke S_3 engine fire	R_1: must shut down affected engine R_2: land immediately	A	S_1, S_2 — S_3 — R_1, R_2	No engine fire extinguishers are located in engine compartment. Pilot needs to know which engine, and panel lights indicate the engine where the problem is located. Also may use hand extinguisher.
Fuselage fire		Crew chief may spot evidence of fire	None	None	10 to 60	S_1 see fire	R_1: land immediately	A	S_1 — R_1	Simple stimulus/response relationship. Also may use hand extinguisher.
Electrical fire		May get intermittent voltage loss	None	May smell burning insulation	0 to 300	S_1. intermittent voltage loss S_2 smell burning insulation S_3 Electrical fire	R_1: isolate faulty circuit by use of circuit breakers and land immediately	A	S_1, S_2 — S_3 — R_1	Sensors for this type of fire may be difficult to install.

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 13 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Chip detector	MASTER CAUTION LIGHT Chip detector light	None	None	None	0 to 30	S_1 chip detector light	R_1 land immediately	B	S_1 —— R_1	Simple stimulus/response relationship
Hydraulic system (first or second stage)	MASTER CAUTION LIGHT First and second stage servo lights Hydraulic pressure indicator	None	Controls may feel slightly sluggish	None	0 to 30	S_1 warning light S_2 hydraulic pressure indicators S_3 hydraulic system failure	R_1 land immediately	B	S_1, S_2 > S_3 — R_1	Pilots consider second stage servo failure to be more critical than first stage servo failure. Second stage operates from main rotor while first stage is driven by No. 1 engine
Utility hydraulic system failure (AFCS, brakes, tail rotor)	MASTER CAUTION LIGHT Utility hydraulic pressure indicator Utility hydraulic servo annunciator light	None	AFCS will go out No brakes if on ground	None	0 to 30	S_1 warning light S_2 utility hydraulic pressure indicator S_3: AFCS goes out S_4. utility hydraulic pressure failure	R_1 land as soon as possible	C	S_1, S_2, S_3 > S_4 — R_1	Pilots do not consider this emergency very critical
Automatic flight control failure (AFCS)	None	None	AFCS goes out Control becomes erratic	None	0 to 5	S_1 kinesthetic inputs S_2 AFCS failure	R_1 disengage AFCS	C	S_1 — S_2 — R_1	Not critical for flight
Pedal damper failure	None	None	Pedal becomes too stiff or too loose Rudder control is erratic	None	0 to 60	S_1 pedal forces S_2 rudder forces S_3 pedal damper failure	R_1 disengage AFCS	C	S_1, S_2 > S_3 — R_1	Not critical for flight.
Hover stick malfunction	Pilot's control authority indicator may fluctuate erratically	Aircraft may not be stable	Control feel may feel force disturbance on body	None	0 to 60	S_1 control indicator S_2 control feel S_3 aircraft may not be stable S_4 hover stick malfunction	R_1 disengage hover stick and continue to fly	A	S_1, S_2, S_3 > S_4 — R_1	Used by aft pilot. Not critical because primary pilot may override aft pilot. Important only during hover

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B Requires quick attention, but there is time for double checking and diagnosis.
C Pilot attends to when time permits.
D Requires knowledge of but no response.

TABLE 13 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Force gradient beeper trim system	None	None	Controls may feel sluggish or overly sensitive depending upon direction of failure	None	0 to 5	S_1: control feel S_2: force gradient beeper trim failure	R_1: turns off AFCS; land as soon as practical	C	S_1 — S_2 — R_1	
Fuel boost pump failure	MASTER CAUTION LIGHT Engine instruments Fuel flow EPR EGT N_1 rpm N_2 rpm Fuel quantity No. 1 or No. 2 fuel pressure light	None	If engine performance is affected, pilot may feel power loss	If engine performance is affected, pilot may hear	0 to 15	S_1 warning light S_2 engine performance S_3 fuel flow S_4 fuel quantity S_5 fuel boost pump failure	R_1: turn off booster pump, open crossfeed switch R_2: if engine has failed, try restart R_3: land as soon as practical	B	S_1, S_2, S_3, S_4 — S_5 — R_1, R_2, R_3	
Electrical power system failure	MASTER CAUTION LIGHT Circuit breakers Failure of lights Generator No. 1 or No 2 light	None	None	None	0 to 15	S_1 generator warning light S_2: circuit breakers S_3 light failure S_4: electrical power system failure	R_1: try to reset generator R_2: return to base	C	S_1, S_2, S_3 — S_4 — R_1, R_2	Not critical to aircraft operation
Electrical failure (d-c)	MASTER CAUTION LIGHT Circuit breakers No 1 or No 2 rectifier	None	None	None	0 to 15	S_1: rectifier warning light S_2: electrical failure (d-c)	R_1: try to reset R_2: turn on battery power; return to base	C	S_1 — S_2 — R_1, R_2	Not immediately hazardous
Instrument power failure	MASTER CAUTION LIGHT Instrument flags on electrical instruments Circuit breakers	None	None	None	0 to 15	S_1 instrument flags S_2 MASTER CAUTION LIGHT S_3 circuit breakers S_4: instrument power failure	R_1: turn on battery R_2 turn off all unnecessary electrical equipment	C	S_1, S_2, S_3 — S_4 — R_1, R_2	

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B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 13 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/ Response Relationship	Comments
Engine fuel control malfunction	MASTER CAUTION LIGHT (if fuel pressure becomes low) Engine instruments	None	May feel engine surge or power setting change	May hear engine change power setting	0 to 15	S_1: engine instruments S_2: fuel flow S_3: fuel pressure S_4: feel change in engine power S_5: hear change of power S_6: engine fuel control malfunction	R_1: shut down N_1 speed lever to ground idle; advance N_1 lever to get both engines at operating rpm, then land	B	S_1, S_2, S_3, S_4, S_5 > S_6 — R_1	May be critical if operator close to ground and carrying load.
Fuel low	MASTER CAUTION LIGHT Fuel quantity Forward fuel low or aft fuel low	None	None	None	0 to 15	S_1: fuel low warning light S_2: fuel quantity S_3: fuel low	R_1: continue to fly if over undesirable terrain R_2: land and refuel if possible or required	B	S_1, S_2 > S_3 < R_1, R_2	Pilots indicate that this light is o-ban on and that normal operation of the aircraft is in a fuel low condition.
Fuel contamination	MASTER CAUTION LIGHT Fuel flow Engine instruments Fuel bypass light, No. 1 or No. 2 engine	None	None	None	0 to 15	S_1: warning lights S_2: fuel contamination	R_1: determine cause of blockage R_2: turn on fuel heater R_3: land if required	B	S_1 — S_2 < R_1, R_2, R_3	
Free turbine N_2 flex cable failure	Engine instruments Rotor rpm	None	May feel one engine surge, while other goes to idle	May hear one engine surge, while other goes to idle	0 to 10	S_1: feel engine surge S_2: hear engine surge S_3: engine instruments S_4: N_2 flex cable failure	R_1: maintain engine control by use of overhead throttles R_2: land as soon as possible	A	S_1, S_2, S_3 > S_4 < R_1, R_2	Sometimes hard to tell which engine control has malfunctioned due to automatic shutdown feature on engines.

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B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 13 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/ Response Relationship	Comments
Rotor speed low	Triple tachometer	Rotor blades will appear to rotate slower than normal Aircraft may start settling	Controls may feel sluggish or sloppy	Rotor rpm may sound low	--	S_1: triple tachometer S_2: rotor speed appears low S_3: rotor rpm sound S_4: rotor rpm low	R_1: land if low altitude and conditions permit R_2: beep up engines to maintain altitude	A	S_1, S_2, S_3 — S_4 — R_1, R_2	
Rotor speed high	Triple tachometer	Rotor blades will appear to be rotating faster than normal	Aircraft vibration may be higher than normal	Rotor rpm may sound high	--	S_1: triple tachometer S_2: rotor speed appears fast S_3: rotor rpm sound S_4: rotor rpm high	R_1: beep down engines R_2: increase collective if possible	A	S_1, S_2, S_3 — S_4 — R_1, R_2	
Overtorquing	Engine torquemeters		Pilot may feel through controls	Engine power may sound different	--	S_1: engine torquemeter S_2: overtorque	R_1: beep down engines R_2: reduce collective if possible	A	S_1 — S_2 — R_1, R_2	
Torque difference between engines	Engine torquemeters Triple tachometer	None	Slight sensation is possible	Small noise difference is possible	--	S_1: engine torquemeter S_2: difference between engines	R_1: beep trim engines to match torques	B	S_1 — S_2 — R_1	
Over gross weight warning	None	Aircraft may settle with power or fail to rise when power is applied	Pilot will feel lack of aircraft response when power is applied	None	--	S_1: response to power application S_2: lack of aircraft response	R_1: if airborne, land using higher than normal power R_2: if on ground, unload part of load	B	S_1 — S_2 — R_1, R_2	
EGT high (No. 1 engine)	Engine air inlet temperature indicator	None	None	None	--	S_1: EGT indicator	R_1: reduce power	B	S_1 — R_1	
EGT high (No. 2 engine)	Engine air inlet temperature indicator	None	None	None	--	S_1: EGT indicator	R_1: reduce power	B	S_1 — R_1	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 13 (continued)

	Perceptual Requirements						Response Requirements			
Failure	Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
N_1 rpm low (No. 1 engine)	Triple tachometer Engine instruments Engine torque	None	Engine vibration changes	Pilot may notice decrease in sound	--	S_1: triple tachometer indicator low rpm S_2: change in engine vibration S_3: low N_1 rpm	R_1: beep up engine rmp; match torques of engines	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1$	
N_1 rpm low (No 2 engine)	Triple tachometer Engine instruments Engine torque	None	Engine vibration changes	Pilot may notice decrease in sound	--	S_1: triple tachometer indicator low rpm S_2: change in engine rpm S_3: low N_1 rpm	R_1: beep up engine rmp; match torques of engines	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1$	
First stage tail rotor servo	MASTER CAUTION LIGHT Warning light First stage servo light	Crew can usually inspect the tail rotor	Pilot will note difficulty of maintaining directional control		0 to 5	S_1: first stage tail rotor servo	R_1: autorotate using smooth decrease in power	A	$S_1 \rightarrow R_1$	
Tail rotor	None	None	Loss of directional control	May conceivably hear rotor fail	0 to 5	S_1: loss of directional control S_2 loss of tail rotor	R_1: land	A	$S_1 \rightarrow S_2 \rightarrow R_1$	Failure may be quite apparent without need for additional alerting devices.
Transmission oil temperature	Transmission oil temperature gauge MASTER CAUTION LIGHT Transmission oil hot light	None	None	None	0 to 30	S_1: warning light S_2: transmission oil temperature indicator S_3: transmission oil temperature high	R_1: land immediately	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1$	
Transmission oil pressure	Transmission oil pressure MASTER CAUTION LIGHT Transmission oil pressure light	None	None	None	0 to 30	S_1 warning light S_2 transmission oil pressure indicator S_3 transmission oil pressure low	R_1 land immediately	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1$	

*A Requires rapid response which takes precedence over all other activities
B Requires quick attention, but there is time for double checking and diagnosis.
C Pilot attends to when time permits
D Requires knowledge of but no response

TABLE 13 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Perceptual Requirements: Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Intermediate transmission oil pressure	MASTER CAUTION LIGHT Intermediate transmission oil pressure light	None	None	None	0 to 30	S_1: warning light S_2: intermediate transmission oil pressure indicator S_3: intermediate transmission oil pressure low	R_1: land immediately	B	$S_1, S_2 > S_3$ — R_1	
Engine anti-ice	MASTER CAUTION LIGHT Engine instruments Engine anti-ice warning light	None	None	None	0 to 30	S_1: engine anti-ice on	R_1: turn off	C	S_1 — R_1	
Heater hot	MASTER CAUTION LIGHT Heater hot warning light	None	Cabin temperature does not increase due to automatic shutoff of heater	None	0 to 30	S_1: heater hot	R_1: turn off	C	S_1 — R_1	
Pilot heat (pilot's or copilot's)	MASTER CAUTION LIGHT Pilot heat warning light	None	None	None	0 to 30	S_1: pilot heat on (pilot's or copilot's)	R_1: turn off	C	S_1 — R_1	
Hoist oil pressure	MASTER CAUTION LIGHT Hoist oil pressure warning light	None	None	None	0 to 30	S_1: hoist oil pressure low	R_1: check hoist oil pressure	C	S_1 — R_1	
Hoist oil temperature	MASTER CAUTION LIGHT Hoist oil temperature warning light	None	None	None	0 to 30	S_1: hoist oil temperature high	R_1: check hoist oil temperature	C	S_1 — R_1	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of base response.

TABLE 13 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Turn and slip (pilot's and co-pilot's)	MASTER CAUTION LIGHT Turn and slip (pilot's and copilot's warning light)	None	None	None	0 to 30	S_1: turn and slip malfunctioning	R_1: check operation of turn and slip indicators	C	S_1 — R_1	
IFF	MASTER CAUTION LIGHT IFF warning light	None	None	None	0 to 30	S_1: IFF inoperative	R_1: check operation of IFF	C	S_1 — R_1	
Rotor brake pressure	MASTER CAUTION LIGHT Rotor brake pressure warning light	None	None	None	0 to 30	S_1: rotor brake pressure low	R_1: check rotor brake pressure	C	S_1 — R_1	
Landing gear kneeled	MASTER CAUTION LIGHT Landing gear kneeled warning light	None	None	None	0 to 30	S_1: landing gear kneeled	R_1: lock landing gear in normal landing position	C	S_1 — R_1	
Leveliser locked	MASTER CAUTION LIGHT Leveliser locked warning light	None	None	None	0 to 30	S_1: leveliser locked	R_1: leave leveliser locked R_2: unlock liveliser	C	S_1 — R_1 S_1 — R_2	
Engine starter on (No. 1 or No. 2)	MASTER CAUTION LIGHT Engine starter on warning light	None	None	None	0 to 30	S_1: engine starter on (No. 1 or No. 2)	R_1: turn off engine starter	B	S_1 — R_1	
APP on	MASTER CAUTION LIGHT APP warning light	None	None	None	0 to 30	S_1: APP on	R_1: turn off APP	B	S_1 — R_1	
Parking brake on	MASTER CAUTION LIGHT Parking brake on warning light	None	None	None	0 to 30	S_1: parking brake on	R_1: release parking brake	C	S_1 — R_1	

*A Requires rapid response which takes precedence over all other activities.
B Requires quick attention, but there is time for double checking and diagnosis.
C Pilot attends to when time permits.
D Requires knowledge of but no response.

TABLE 13 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
External power connected	MASTER CAUTION LIGHT External power connected warning light	None	None	None	0 to 30	S_1: external power connected	R_1: disconnect external power	C	S_1 —— R_1	
Rotor brake on	MASTER CAUTION LIGHT Rotor brake on warning light	None	Rotor slows down	Rotor sound changes	0 to 30	S_1: rotor brake warning light S_2: rotor vibration S_3: rotor sound S_4: rotor brake on	R_1: release rotor brake R_2: leave rotor brake on	A	S_1, S_2, S_3 > S_4 < R_1, R_2	
Hook unlocked	MASTER CAUTION LIGHT Hook unlocked warning light	None	None	None	0 to 30	S_1: hook unlocked	R_1: lock hook	C	S_1 —— R_1	
Fuel temperature low	MASTER CAUTION LIGHT Fuel temperature low warning light	None	None	None	0 to 30	S_1: fuel temperature low	R_1: descend to lower altitude	B	S_1 —— R_1	
Auto-hook release	MASTER CAUTION LIGHT Auto-hook release warning light	None	None	None	0 to 30	S_1: auto-hook release armed	R_1: turn off hook release arming switch	C	S_1 —— R_1	
Tail skid up	MASTER CAUTION LIGHT Tail skid up warning light	None	None	None	0 to 30	S_1: tail skid up	R_1: lower tail skid	C	S_1 —— R_1	
Four-part jettison armed	MASTER CAUTION LIGHT Four-part jettison warning light	None	None	None	0 to 30	S_1: four-part jettison actuated	R_1: does nothing	D	S_1 —— R_1	

*A. Requires rapid response which takes precedence over all other activities
B. Requires quick attention, but there is time for double checking and diagnosis
C. Pilot attends to when time permits
D. Requires knowledge of but no response

TABLE 14

Analysis of OV-1 Emergency Tasks

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Engine failure (left or right engine)	Engine instruments N_1 rpm N_2 rpm EPR EGT Fuel flow Torque-meter	Sees aircraft yaw Throttle position Sees prop slow down or stop	Feels aircraft yaw Control of heading is more difficult (requires rudder) Pilot feels aircraft slow down	Pilot hears engine slow down or stop Sound of air stream reduces	0 to 5	S_1: N_1 rpm indicator S_2: torque-meter S_3: aircraft yaw S_4: engine sound S_5: control feel S_6: engine failure (left or right)	R_1: feather prop on dead engine and apply power to good engine R_2: try re-start if failure is not due to mechanical reasons R_3: land as soon as possible	A	$S_1, S_2, S_3, S_4, S_5 \rightarrow S_6 \rightarrow R_1, R_2, R_3$	
Engine failure (both engines)	Engine instruments N_1 rpm N_2 rpm EPR EGT Fuel flow Torque-meters	Pilot sees aircraft descend Throttle position Pilot can see both Props slow down and stop	Feels aircraft descend Aircraft slows down	Pilot hears engines quit Sound of air-stream reduces	0 to 2	S_1: N_1 rpm indicator S_2: torque-meters S_3: aircraft descends S_4: kinesthetic cues S_5: sound of engines S_6: engine failure (both engines)	R_1: jettison external stores R_2: feather both props R_3: try re-start if failure is not due to mechanical reasons R_4: emergency landing	A	$S_1, S_2, S_3, S_4, S_5 \rightarrow S_6 \rightarrow R_1, R_2, R_3, R_4$	This problem is immediately apparent without an additional alerting device.
Engine fire	Fire emergency control handle light Engine instruments EGT N_1 rpm N_2 rpm EPR Fuel flow	Pilot or observer may or may not see fire, depending upon location in engine If engine performance is affected, then pilot will see other visual stimuli associated with engine	None, unless engine performance is affected	May smell fuel or burning material If engines are affected, then engine noise will change	0 to 30	S_1: fire control handle S_2: sees flame or smoke S_3: engine fire (left or right)	R_1: remove power from affected engine; discharge both extinguisher bottles into fire R_2: if fire light goes out when power is removed from engine; wait, then attempt to return power slowly R_3: land immediately	A	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3$	A voice warning for this emergency would be most useful. Warning should indicate which engine is affected.

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 14 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Perceptual Requirements: Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Fuselage fire	None	Possibly the pilot and observer may see fire, but visibility is not good	None	Possibly may hear or smell burning	0 to 300	S_1: sees smoke S_2: smells smoke S_3: fuselage fire	R_1: try to isolate fire R_2: try to control fire R_3: eject if necessary R_4: land immediately	A	S_1, S_2 — S_3 — R_1, R_2, R_3, R_4	A sensor system for detection of fuselage fires is under consideration. Thus, this warning is feasible and desirable due to location of main fuel cells in fuselage and poor visibility.
Wing fire	None	Possibly the pilot and observer may see fire	None	May hear or smell burning	0 to 300	S_1: sees smoke or fire S_2: smells smoke S_3: wing fire	R_1: attempt to put out fire by diving aircraft or slipping away from fire R_2: eject R_3: land	A	S_1, S_2 — S_3 — R_1, R_2, R_3	Sensors are not currently being considered for this emergency; therefore, a voice warning may not be possible.
Engine chip	MASTER CAUTION LIGHT No. 1 or No. 2 engine chip warning light	May check engine instruments Oil pressure Oil temperature EPR N_1 rpm N_2 rpm	None	None	0 to 30	S_1: engine chip warning light S_2: engine chip (left or right)	R_1: jettison external stores R_2: determine which engine is affected R_3: shut down affected engine R_4: reduce power on affected engine R_5: land as soon as possible	B	S_1 — S_2 — R_1, R_2, R_3, R_4, R_5	
Hydraulic failure	Hydraulic pressure indicator Landing gear warning light	If gear is actuated, there is no altitude change	Flap control becomes erratic and difficult Landing gear may not extend properly (hence, lack of altitude change)	May smell hydraulic fluid Absence of gear or flap sound	0 to 900	S_1: aircraft performance S_2: hydraulic pressure indicator S_3: hydraulic failure	R_1: bring flaps up R_2: blow down landing gear using emergency gear release	B	S_1, S_2 — S_3 — R_1, R_2	Warning is important only prior to landing.

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 14 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
AFCS (automatic flight control system)	MASTER CAUTION LIGHT Circuit breakers are affected AFCS warning light	Erratic flight of aircraft can occur	Pilot may notice faulty system through control feel		0 to 300	S_1: AFCS warning light S_2: aircraft flight S_3: AFCS failure	R_1: check circuit breaker of AFCS to see that AFCS is engaged R_2: disengage AFCS	C	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2$	
Fuel boost pumps (both pumps in one tank)	MASTER CAUTION LIGHT Fuel flow Fuel pressure Engine instruments Fuel quantity Fuel pumps warning light	Aircraft may descend if engine performance is affected (see engine failure); otherwise none	Pilot will feel only if engine performance is affected (see engine failure)	None unless engine performance is affected (see engine failure)	0 to 60	S_1: fuel pump warning light S_2: engine performance S_3: fuel boost pump warning light	R_1: may have to try restarting engine if flameout occurs R_2: descend below 6000 feet to retain use of engines R_3: land as soon as possible	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3$	
Engine-driven fuel pump	MASTER CAUTION LIGHT Fuel pressure indicator Fuel flow Engine instruments Fuel quantity No. 1 or No. 2 fuel pressure high		None	None	0 to 30	S_1: No. 1 or No. 2 fuel pressure high warning light S_2: engine performance S_3: engine-driven fuel pump	R_1: monitor engine instruments R_2: return to base and land	B	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2$	
Electrical power system failure	MASTER CAUTION LIGHT Circuit breakers No. 1 or No. 2 generator warning light	Lights and other electrically driven equipment may fail	None	None	0 to 5	S_1: No. 1 or No. 2 generator warning light S_2: failure of other electrical instruments S_3: electrical power failure	R_1: try to reset generators R_2: turn off unnecessary equipment R_3: land at nearest base	C	$S_1, S_2 \rightarrow S_3 \rightarrow R_1, R_2, R_3$	

*A Requires rapid response which takes precedence over all other activities
B Requires quick attention, but there is time for double checking and diagnosis
C Pilot attends to when time permits.
D Requires knowledge of but no response

TABLE 14 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Other Visual	Kinesthetic	Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Instrument power failure	MASTER CAUTION LIGHT Circuit breakers Flags in electrically driven instruments may appear Instrument power warning light	None	None		0 to 5	S_1: flags on electrically driven instruments S_2: instrument power warning light S_3: instrument power failure	R_1: try to reset circuit breakers R_2: turn off unnecessary equipment R_3: switch to battery power, continue mission, and land when convenient	C	$S_1, S_2 > S_3 < R_1, R_2, R_3$	
Failure of automatic fuel metering control	MASTER CAUTION LIGHT Fuel flow Engine instruments No. 1 or No. 2 fuel pressure high	None	Symptoms of engine failure	Symptoms of engine failure	0 to 30	S_1: No. 1 or No. 2 fuel emergency warning light S_2: fuel flow S_3: engine performance S_4: fuel metering control failure (No. 1 or No. 2)	R_1: set fuel control to emergency; land as soon as possible	B	$S_1, S_2, S_3 > S_4 — R_1$	
Fuel low level	MASTER CAUTION LIGHT Fuel quantity Fuel flow indicator Fuel low level warning light	None	None	None	0 to 30	S_1: fuel low-level warning light S_2: fuel quantity S_3: fuel low	R_1: check fuel remaining and fuel flow R_2: reduce power to economical cruise R_3: check terrain and altitude R_4: land as soon as possible	B	$S_1, S_2 > S_3 < R_1, R_2, R_3, R_4$	
Electrical fire	None	May see arcing of wires and sparks Symptoms of electrical power loss		May hear arcing of wires May smell burning insulation	0 to 300	S_1: sees fire S_2: smells smoke S_3: symptoms of electrical failure S_4: electrical fire	R_1: isolate fire by pulling circuit breaker R_2: control fire R_3: land as soon as possible	B	$S_1, S_2, S_3 > S_4 < R_1, R_2, R_3$	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

TABLE 14 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/Response Relationship	Comments
Fuel strainer	MASTER CAUTION LIGHT Fuel flow Engine instruments Fuel strainer warning light	None	None	None	0 to 30	S_1: fuel strainer warning light S_2: fuel strainer clogged	R_1: land as soon as possible	C	S_1 — S_2 — R_1	
Wheels caution light	Wheels caution light Gear handle	Landing gear handle	Control of aircraft does not feel like gear is extended	None	0 to 30	S_1: wheels warning light S_2: landing gear not down	R_1: check gear handle position R_2: if hydraulics failure has occurred, blow gear down using emergency gear extended procedure; land	B	S_1 — S_2 — R_1, R_2	Important only during landing. Wheels warning light will not come on until the flap setting is 15 degrees or more. In the case of no-flap landings, the wheels light would not appear. Perhaps this warning should be based upon airspeed and altitude.
Drop tank caution light (left or right)	MASTER CAUTION LIGHT Left or right drop tank warning light	Drop tank release switch	Aircraft will yaw if tanks do not release together	None	0 to 5	S_1: left or right drop tank warning light S_2: aircraft yaws S_3: drop tank malfunction (left or right)	R_1: try to reactivate jettison control R_2: if unable to remove tanks, land at nearest base to remove	B	S_1, S_2 — S_3 — R_1, R_2	
Propeller failure	Tachometer, propeller	Propeller may be seen	Aircraft will yaw	Propeller noise will change	0 to 5	S_1: sees propeller fail S_2: aircraft yaw S_3: propeller failure	R_1: shut down engine, land immediately	A	S_1, S_2 — S_3 — R_1	Sensors are not available. The pilot is immediately aware of what has happened, and does not need to be alerted.
Oil pressure loss	Oil pressure gauge	None	None	None	--	S_1 oil pressure indicator (left or right engine) S_2: oil pressure low	R_1: shut down affected engine R_2: reduce power on affected engine R_3: land immediately	B	S_1 — S_2 — R_1, R_2, R_3	

*A Requires rapid response which takes precedence over all other activities
B Requires quick attention, but there is time for double checking and diagnosis
C Pilot attends to when time permits
D Requires knowledge of but no response.

TABLE 14 (continued)

Failure	Perceptual Requirements: Instruments and Annunciators	Perceptual Requirements: Other Visual	Perceptual Requirements: Kinesthetic	Perceptual Requirements: Auditory or Olfactory	Estimated Time to Detect (seconds)	Diagnostic Elements	Response Requirements: Response Options	Response Requirements: Mandatory Time to Respond*	Stimulus/ Response Relationship	Comments
Stall	Airspeed indicator Altimeter	Horizon will change	Controls feel sloppy Aileron control is ineffective Directoral control difficult	Engines may labor Sound of passing air changes	0 to 5	S_1: aircraft control S_2: horizon S_3: engine sound S_4: stall	R_1: neutralize controls; apply power; maintain directional control using rudders	A	S_1, S_2, S_3 — S_4 — R_1	Sensors are not currently being considered for this emergency.
EGT high (low)	EGT	None	May feel power loss	May hear power loss	0 to 60	S_1: EGT indicator S_2: EGT low	R_1: reset power	B	S_1 — S_2 — R_1	Used in diagnosis of engine failure.
N_1 rpm low (left engine)	N_1 tachometer	None	Will feel power loss	Will hear power loss	0 to 5	S_1: N_1 rpm indicator (left engine) S_2: N_1 rpm low	R_1: increase power R_2: shut down engine and try to restart	B	S_1 — S_2 — R_1, R_2	Used in diagnosis of engine failure.
N_1 rpm low (right engine)	N_1 tachometer	None			0 to 5	S_1: N_1 rpm indicator (right engine) S_2: N_1 rpm low	R_1: increase power R_2: shut down engine and try to restart	B	S_1 — S_2 — R_1, R_2	Used in diagnosis of engine failure.
EPR low (left or right)	EPR indicator	None			0 to 5	S_1: EPR indicator (left or right) S_2: EPR low	R_1: increase power	B	S_1 — S_2 — R_1	Used in diagnosis of engine failure.
Torque low (left or right)	Torque	None			0 to 5	S_1: Torquemeter (left or right) S_2: Torque low (left or right)	R_1: increase power	B	S_1 — S_2 — R_1	Used in diagnosis of engine failure.
Fuel flow low (left or right)	Fuel flow indicator	None			0 to 10	Diagnostic for boost pump failure and fuel pump failure S_1: fuel flow indicator (left or right) S_2: fuel flow low	R_1: increase power R_2: descend below 6000 feet R_3: shut down engine	B	S_1 — S_2 — R_1, R_2, R_3	

*A: Requires rapid response which takes precedence over all other activities.
B: Requires quick attention, but there is time for double checking and diagnosis.
C: Pilot attends to when time permits.
D: Requires knowledge of but no response.

APPENDIX C

PILOT SURVEY DATA

TABLE 28

UH-1 Pilot Ranking

Paired-Comparison Technique				Ranking Technique			
Failure	No. of times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
Engine oil pressure	391	Fuselage fire	884	Transmission oil pressure	2.8	Fuselage fire	2.2
Transmission oil temperature high	367	Engine failure	788	Engine oil pressure	4.5	Engine failure	3.8
Fuel pressure low	358	Transmission oil pressure low	585	Transmission oil hot	4.5	Transmission oil pressure	5.6
Hydraulic pressure low	264	Transmission chips	584	Chip detector	6.6	Engine oil pressure	6.2
Chips	247	Transmission oil temperature high	494	Engine fuel pump	6.7	Transmission oil hot	6.9
Fuel low	196	Engine chips	469	Hydraulic pressure No. 1	7.6	Transmission chip detector	7.3
Transmission oil pressure high	186	Engine oil pressure low	460	Hydraulic pressure No. 2	8.6	Governor emergency	8.3
Transmission oil pressure low	124	Chip detector	423	Fuel filter bypass	9.9	Engine chips	9.5
		Fuel pressure low	340	Left fuel boost	10.4	Chip detector	9.5
		Hydraulic pressure low	213	Engine ice detector	10.5	Tail rotor chips	9.9
		Fuel low	156	Right fuel boost	10.8	Engine fuel pump	10.5
				20-minute fuel	11.1	Hydraulic pressure No. 1	11.7
				Generator (d-c)	11.9	Hydraulic pressure No. 2	12.1
				Inverter	12.2	Fuel filter bypass	14.7
				Auxiliary fuel low	14.2*	Left fuel boost	15.1
				External power	15.6**	Right fuel boost	15.7
						Engine ice detector	15.8
						20-minute fuel	16.3
						Generator (d-c)	16.7
						Inverter	16.9
						Auxiliary fuel low	18.6*
						External power	21.1**

*Of pilots sampled, 25 to 50% indicated no voice warning is necessary

**Of the pilots sampled, 50% or more indicated no voice warning is necessary

TABLE 29

AH-1G Pilot Ranking

Paired-Comparison Technique				Ranking Technique			
Failure	No. of Times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
Transmission oil pressure	148	Engine failure	310	Transmission oil pressure	6.5	Engine failure	4.7
Engine oil pressure	113	Transmission oil pressure	281	Engine oil pressure	5.9	Engine oil pressure	6.2
Chip detector	102	Rotor rpm abnormal	252	Transmission oil hot	9.5	Transmission oil pressure	6.6
Transmission oil hot	80	Engine oil pressure	244	Governor emergency	9.5	Rotor rpm abnormal	8.5
Hydraulic pressure No. 2	52	Transmission oil hot	214	Engine fuel pump	11.3	Transmission oil hot	10.2
Hydraulic pressure No. 1	19	Chip detector	212	Chip detector	12.0	EGT high	11.5
10% fuel	18	EGT high	172	Engine oil bypass	12.8	Engine oil bypass	12.4
		Hydraulic pressure No. 2	139	Transmission oil bypass	15.1	Governor emergency	12.8
		Caution panel	119	Engine air	16.7	Engine fuel pump	13.0
		Hydraulic pressure No. 1	113	Hydraulic pressure No. 2	16.9	Chip detector	13.0
		SAS abnormal	30*	Hydraulic pressure No. 1	17.0	Transmission oil bypass	13.6
				Fuel filter	17.1	Hydraulic pressure No. 2	15.6
				Forward fuel boost	20.5	Engine air	15.8
				10% fuel	20.5	Fuel filter	16.6
				Instrument inverter	22.1	Hydraulic pressure No. 1	17.4
				Aft fuel boost	22.2	Forward fuel boost	18.6

TABLE 29 (continued)

Paired-Comparison Technique				Ranking Technique			
Failure	No. of Times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
				Generator (d-c)	22.4	Caution panel	18.7
				IFF	31.0*	Aft fuel boost	18.7
				External power	32.0*	10% fuel	21.1
						Generator (d-c)	21.5
						Instrument inverter	22.3
						SAS abnormal	23.9*
						IFF	29.2*
						External power	29.5*

*Of the pilots sampled, 50% or more indicated no voice warning is necessary

TABLE 30

CH-47 Pilot Ranking

Paired-Comparison Technique				Ranking Technique			
Failure (reduced list)	No. of Times First	Failure (additional warnings)	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
Both hydraulic systems	263	Engine fire	386	Engine fire	1.1	Engine fire	2.2
Engine fire	209	Fuselage fire	364	Transmission oil pressure	3.3	Fuselage fire	4.5
Transmission oil pressure	200	Transmission oil pressure	324	Transmission chips	4.2	Electrical fire	5.1
Hydraulic system	177	Engine failure	322	Hydraulic system	4.3	Hydraulic system	6.8
Transmission chips	169	Transmission chips	298	Transmission oil temperature	4.8	Transmission oil pressure	6.9
Transmission oil temperature	143	Hydraulic system	292	Engine chips	5.8	Transmission oil temperature	7.0
Engine chips	128	Transmission oil temperature	273	Oil low	7.9	Engine failure	7.1
Oil low	97	Engine chips	248	Fuel pressure low	8.7	Transmission chips	7.2
Fuel pressure low	77	Rotor speed abnormal	179	Fuel low	9.7	Engine chips	8.9
Generator (a-c)	62	Oil low	172	Generator (a-c)	9.8	Oil low	12.5
Fuel low	53	Overtorque	158	Transformer rectifier	10.2	Engine beep trim switch	12.8
Stabilizer augmentation system	49	Fuel pressure low	150	Stabilizer augmentation system	12.1	Utility hydraulic system	13.2
Transformer rectifier	40	Utility hydraulic system	147	Heater hot	13.5*	Fuel pressure low	13.5
		Transformer rectifier	142	Parking brake	13.9	Rotor speed abnormal	13.8
		Fuel low	131	Wheel dephased	14.7*	Generator (a-c)	14.4
		Generator (a-c)	130	External power on (a-c)	14.9**	Overtorque	15.0

TABLE 30 (continued)

Paired-Comparison Technique				Ranking Technique			
Failure (reduced list)	No. of Times First	Failure (additional warnings)	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
		Stabilizer augmentation system	90	Cargo hook open	15.2*	Transformer rectifier	15.6
		Over gross weight	79*	External power on (d-c)	15.6**	Longitudinal cyclic trim	17.2*
		Fuel boost pump	66*			Fuel low	18.1
		Controls not centered	40**			Stability augmentation system	19.9
						Fuel boost pump	19.7*
						Heater hot	20.2*
						Wheel dephased	20.6*
						Over gross weight	21.4*
						Parking brake	21.4
						External power on (a-c)	23.9**
						Cargo hook open	24.0*
						External power on (d-c)	25.1**
						Controls not centered	25.5**

*Of pilots sampled, 25 to 50% indicated no voice warning is necessary

**Of pilots sampled, 50% or more indicated no voice warning is necessary

TABLE 31

CH-54 Pilot Ranking

Paired-Comparison Technique				Ranking Technique			
Failure	No. of Times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
Transmission oil pressure	240	Fuselage fire	429	Transmission oil pressure	2.6	Fuselage fire	2.1
Engine fire	216	Transmission oil pressure	429	Engine fire	2.9	Engine fire	2.2
Intermediate transmission oil pressure	174	Engine fire	427	Hydraulic failure	4.9	Transmission oil pressure	4.8
Engine fuel control malfunction	172	Intermediate transmission oil pressure	335	Transmission oil temperature	5.2	Transmission oil temperature	6.2
Transmission oil temperature	170	Engine failure	318	Intermediate transmission pressure	6.1	Engine failure	6.8
Chip detector	158	Transmission oil temperature	307	Chip detector	6.2	Intermediate transmission pressure	6.9
Hydraulic failure	152	Chip detector	295	Engine fuel control	7.2	Hydraulic failure	8.5
First stage tail servo	103*	Engine fuel control	291	First stage tail servo	9.1*	Engine fuel control	9.9
Fuel contamination	100	Hydraulic failure	285	Fuel contamination	9.2	N_2 flex cable	10.5
Utility hydraulic system	82	N_2 flex cable	266	Utility hydraulic system	11.1	Overtorque	13.2
Electrical power supply	71*	Overtorque	221	Electrical power system	12.1*	Fuel contamination	14.2
Electrical failure (d-c)	49*	Rotor speed abnormal	218	Hoist oil temperature	12.2	First stage tail servo	14.2*
Fuel low	20*	First stage tail servo	202*	Hoist oil pressure	13.7	Fuel boost pump	14.2*
		Fuel contamination	201	Electrical system (d-c)	15.1*	Rotor speed abnormal	14.7
		Utility hydraulic	159	Engine starter on	15.2*	Utility hydraulic system	16.1
		Electrical power failure	149*	Rotor brake pressure	16.1*	Electrical power failure	17.2*
		Over gross weight	119	Heater hot	16.2*	Automatic flight control system	18.2*

TABLE 31 (continued)

Paired-Comparison Technique				Ranking Technique			
Failure	No. of Times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
		Automatic flight control system	117*	Fuel low	17.9*	Electrical failure (d-c)	19.1*
		Electrical failure (d-c)	114*	Landing gear kneeled	18.1*	Parking brake on	19.1*
		Fuel boost pump	82*	Parking brake on	20.0*	Over gross weight	20.1
		Torque difference	75*	APP on	20.3*	Rotor brake pressure	20.2*
		Fuel low	51*	Leveliser locked	20.8*	Hoist oil pressure	20.2
				External power connected	21.8**	Fuel low	21.1*
				Pitot heat	22.0*	Torque difference	21.2*
				Turn and slip	23.1**	Chip detector	21.2
				IFF	24.1**	Engine starter on	22.1*
						Heater hot	22.1*
						Landing gear kneeled	23.2*
						Hoist oil temperature	23.6
						Leveliser locked	27.1*
						APP on	29.2*
						Engine anti-ice	29.8*
						External power connected	30.9**
						Turn and slip	32.1**
						Pitot heat	32.1*
						IFF	33.1**

*Of pilots sampled, 25 to 50% indicated no voice warning is necessary

**Of the 22 pilots, 50% or more indicated no voice warning is necessary

TABLE 32

OV-1 Pilot Ranking

Paired-Comparison Technique				Ranking Technique			
Failure	No. of Times First	Failure	No. of Times First	Failure	Mean Rank	Failure	Mean Rank
Engine fire	194	Fuselage fire	257	Engine fire	1.5	Fuselage fire	2.5
Wheels	158	Engine fire	251	Wheels	3.1	Wing fire	2.6
Fuel low	131	Both engines failed	210	Engine-driven fuel pump	3.8	Engine fire	5.0
Engine-driven fuel pump	131	Engine failure	197	Fuel pressure high	5.4	Engine failure	5.6
Fuel pressure high	115	Wheels	188	Fuel low	5.9	Electrical fire	8.3
Engine chips	110	Oil pressure low	187	Inverter	7.2	Propeller failure	8.4
Electrical power system	110	Engine-driven fuel pump	158	Fuel boost pump	7.6	Engine-driven fuel pump	10.4
Inverter	108	Fuel pressure high	135	Fuel strainer	7.7	Wheels	11.2
Fuel boost pump	91	Hydraulic system	134	Electrical power system	7.9	Hydraulic system	11.3
Fuel emergency	71	Fuel low	118	Engine chips	8.4	Fuel low	15.5
Fuel strainer	61	Engine chips	112	Fuel emergency	8.7*	Fuel pressure high	15.7
IFF	36*	Electrical power	105	Drop tank	11.2*	Engine chips	16.0
		Inverter	104	IFF	12.8*	Electrical power system	16.1
		Fuel boost pump	95	AFCS	12.9	Inverter	16.3
		Fuel strainer	81			Fuel boost pump	16.4
		Fuel emergency	80*			Engine ice	16.4
		Stall warning	66			Fuel strainer	17.8
		Drop tank	37*			Fuel emergency	19.5*
		AFCS	33			Stall warning	20.1
						Drop tank	20.2*
						AFCS	23.5
						IFF	24.5*

*Of pilots sampled, 25 to 50% indicated no voice warning is necessary

TABLE 53

Responses to General Questions

1. Should the pilot have the option of disabling the voice-warning system?

	Yes	No
UH-1	74	14
AH-1G	29	4
CH-47	20	1
CH-54	21	1
OV-1	13	2
Total	157	22

2. Do you object to having a woman's voice give the voice warning?

	Yes	No
UH-1	4	84
AH-1G	2	31
CH-47	0	21
CH-54	2	20
OV-1	0	15
Total	8	171

3. If you experienced an engine fire, is it important or necessary for the voice-warning message to tell you which engine has the fire?

	Yes	No
UH-1	--	--
AH-1G	--	--
CH-47	12	9
CH-54	20	2
OV-1	12	2
Total	44	13

4. If so, which engine is most important to hear about first?

	Left	Right	Either
UH-1	--	--	--
AH-1G	--	--	--
CH-47	--	--	18
CH-54	12	0	10
OV-1	4	0	10
Total	16	0	38

5. If you experience a single hydraulic failure, is it important or necessary for the voice-warning message to tell you which system has failed?

	Yes	No
UH-1	44	44
AH-1G	17	16
CH-47	13	8
CH-54	15	7
OV-1	--	--
Total	89	75

TABLE 33 (continued)

6. If both of your hydraulic systems were failing, would you want a voice-warning message to tell you that both systems were failing?

	Yes	No
UH-1	80	8
AH-1G	32	1
CH-47	20	1
CH-54	21	1
OV-1	--	--
Total	153	11

7. Would you prefer that the voice-warning message tell you about only one hydraulic failure at a time?

	Yes	No
UH-1	32	56
AH-1G	5	27
CH-47	4	16
CH-54	9	13
OV-1	--	--
Total	50	112

8. If you experienced a double engine failure, would you want a voice-warning message to tell you that both engines were failing?

	Yes	No
UH-1	--	--
AH-1G	--	--
CH-47	17	4
CH-54	19	3
OV-1	13	1
Total	49	8

9. In terms of consequences, which engine failure is the most critical?

	Left	Right	Either
UH-1	--	--	--
AH-1G	--	--	--
CH-47	--	--	20
CH-54	20	--	2
OV-1	9	1	4
Total	29	1	26

10. If you experienced a single engine failure, is it important or necessary for the voice-warning message to tell you which engine failed?

	Yes	No
UH-1	--	--
AH-1G	--	--
CH-47	13	8
CH-54	17	5
OV-1	10	5
Total	40	18

TABLE 33 (continued)

11. Given a choice between a single message, such as "engine failure" or a series of messages such as "N_1 rpm low," "EGT low," "fuel flow stopped," would you prefer a single message such as "engine failure" or a series of messages containing information about the engine parameters?

	Single	Series of Messages	Both
UH-1	52	10	26
AH-1G	23	2	8
CH-47	20	0	1
CH-54	16	3	3
OV-1	10	2	3
Total	121	17	41

12. Given a single message about EGT, would you want to hear "EGT high," "EGT low," or would you want to know "EGT abnormal?"

	High	Low	Both	Abnormal
UH-1	16	0	34	38
AH-1G	5	0	9	19
CH-47	7	0	7	7
CH-54	8	0	5	9
OV-1	4	0	2	8
Total	40	0	57	81

13. Given a single message about N_1 rpm, would you want to know "N_1 rpm high," "N_1 rpm low," or would you want to know "N_1 rpm abnormal?"

	High	Low	Both	Abnormal
UH-1	4	9	49	25
AH-1G	0	2	12	19
CH-47	0	3	10	8
CH-54	2	0	6	14
OV-1	1	2	4	8
Total	7	16	81	74

14. Given a single message about fuel pressure, would you want to know "fuel pressure high," "fuel pressure low," or would you want to know "fuel pressure abnormal?"

	High	Low	Both	Abnormal
UH-1	2	21	35	31
AH-1G	0	7	5	21
CH-47	0	8	3	10
CH-54	0	5	4	13
OV-1	0	0	3	12
Total	2	41	50	87

15. Given a single message about transmission oil pressure, would you want to know "transmission oil pressure high," "transmission oil pressure low," or would you want to know "transmission oil pressure abnormal?"

	High	Low	Both	Abnormal
UH-1	3	13	45	27
AH-1G	0	2	17	14
CH-47	1	7	6	7
CH-54	0	2	9	11
OV-1	0	2	3	8
Total	4	26	80	67

TABLE 33 (continued)

16. Given a single message about engine oil pressure, would you want to hear "engine oil pressure high," "engine oil pressure low," or would you want to know "engine oil pressure abnormal?"

	High	Low	Both	Abnormal
UH-1	0	18	43	27
AH-1G	0	3	18	12
CH-47	0	6	8	7
CH-54	0	2	9	11
OV-1	0	5	2	8
Total	0	34	80	65

17. Given a single message about engine oil quantity, would you want to know "engine oil quantity high," "engine oil quantity low," or would you want to hear "engine oil quantity abnormal?"

	High	Low	Both	Abnormal
UH-1	0	37	29	22
AH-1G	0	11	13	9
CH-47	0	12	7	2
CH-54	0	10	8	4
OV-1	0	9	4	2
Total	0	79	61	39

18. Given a single message about torque, would you rather hear "torque high," "torque low," or would you want to hear "torque abnormal?"

	High	Low	Both	Abnormal
UH-1	28	1	32	27
AH-1G	22	0	4	7
CH-47	13	0	3	5
CH-54	10	0	5	7
OV-1	2	3	1	9
Total	75	4	45	55

19. Given a single message about rotor rpm, would you rather hear "rotor rpm high," "rotor rpm low," or would you want to hear "rotor rpm abnormal?"

	High	Low	Both	Abnormal
UH-1	2	13	62	11
AH-1G	1	3	17	12
CH-47	1	1	10	9
CH-54	0	2	11	9
OV-1	--	--	--	--
Total	4	19	100	41

20. To ensure that the voice-warning system is heard, muting other communications (air-to-air, air-to-ground, intercom, etc.) has been recommended (meaning the other communication could still be heard but that the voice-warning system could be distinguished). Would you want muting in a voice-warning system for the (type) vehicle?

	Yes	No
UH-1	69	19
AH-1G	26	6
CH-47	16	5
CH-54	17	5
OV-1	13	2
Total	141	37

TABLE 33 (continued)

21. Should voice-warning messages go to every crew member?

	Yes	No
UH-1	71	17
AH-1G	31	2
CH-47	18	3
CH-54	21	1
OV-1	13	2
Total	154	25

22. Would you want an automatic volume control device on the voice-warning system to ensure that you heard the message?

	Yes	No
UH-1	78	9
AH-1G	29	4
CH-47	18	3
CH-54	20	2
OV-1	14	1
Total	159	19

23. Assuming that 9 times out of 10 a chip detector warning is a false alarm, would you recommend the removal of the chip detector sensor?

	Yes	No
UH-1	12	76
AH-1G	2	30
CH-47	1	20
CH-54	1	21
OV-1	3	12
Total	19	159

24. Should the voice warning give the desired corrective action as well as the fault?

	Yes	No
UH-1	25	63
AH-1G	14	19
CH-47	4	17
CH-54	5	17
OV-1	3	12
Total	51	128

25. If the message only said to check the caution warning panel, would you consider this to be a sufficient warning?

	Yes	No
UH-1	48	39
AH-1G	18	14
CH-47	15	5
CH-54	10	12
OV-1	5	10
Total	96	80

TABLE 33 (continued)

26. Would the voice-warning system eliminate the need for a visual annunciator panel?

	Yes	No
UH-1	2	86
AH-1G	3	30
CH-47	0	21
CH-54	0	22
OV-1	0	15
Total	5	174

27. Would a man's voice in the presentation of a warning be obscured by the communications which normally come into your headset?

	Yes	No
UH-1	67	21
AH-1G	29	3
CH-47	17	4
CH-54	19	2
OV-1	11	3
Total	143	33

28. Would a voice-warning system in a (vehicle) reduce the burden of fault detection through instrument panel checks?

	Yes	No
UH-1	56	32
AH-1G	19	14
CH-47	6	14
CH 54	9	13
OV-1	9	6
Total	99	79

29. Should the voice-warning system be duplicated in the form of a visual annunciator panel?

	Yes	No
UH-1	72	15
AH-1G	21	11
CH-47	16	5
CH-54	15	6
OV-1	12	2
Total	136	39

30. How often do you need to request a radio transmission to be repeated?

	Never	Sometimes	Frequently
UH-1	1	79	8
AH-1G	4	26	3
CH-47	0	17	4
CH-54	0	21	1
OV-1	0	14	1
Total	5	157	17

TABLE 33 (continued)

31. Circle the voice type which you prefer for voice-warning messages.		Male	Female
	UH-1	7	81
	AH-1G	2	29
	CH-47	1	20
	CH-54	2	20
	OV-1	2	13
	Total	14	163
32. Is there a need for a voice warning for a double hydraulic system failure?		Yes	No
	UH-1	63	25
	AH-1G	26	7
	CH-47	16	5
	CH-54	10	11
	OV-1	0	0
	Total	115	48
33. Is there a need for a voice warning for the failure of both engines?		Yes	No
	UH-1	0	0
	AH-1G	0	0
	CH-47	14	7
	CH-54	10	12
	OV-1	0	0
	Total	24	19

TABLE 34

Instances Where More Than 25% of Pilots Sampled Indicated Response to an Emergency Depends on the Mission Phase

Vehicle	Failure	Mission Phase	Pilots Indicating Different Response	Total Pilots
UH-1	Twenty-minute fuel	Takeoff	22	88
	Engine failure	Takeoff	24	
	Governor emergency	Takeoff	25	
AH-16	Rotor rpm abnormal	Takeoff	14	33
	EGT high	Takeoff	10	
	Engine failure	Takeoff	9	
CH-47	Engine fire	Takeoff	6	21
	Electrical fire	Takeoff	6	
	Engine failure	Takeoff and landing	15, 6	
	Transmission oil pressure	Takeoff	6	
	Engine chips	Takeoff	6	
	Oil low	Takeoff	6	
	Beep trim switch	Takeoff	9	
CH-54	Hydraulic failure	Takeoff	6	22
	Engine failure	Takeoff	10	
	Fuel low	Takeoff	9	
	Chip detector	Takeoff	7	
	First stage tail rotor servo	Takeoff	6	
	Engine fuel control	Takeoff	7	
	Tail rotor failure	Takeoff, cruise, and landing	9, 8, 8	
	External power connected	Takeoff	9	
	Over gross weight	Takeoff	7	

TABLE 34 (continued)

Vehicle	Failure	Mission Phase	Pilots Indicating Different Response	Total Pilots
OV-1	Fuselage fire	Landing	8	16
	Wing fire	Cruise and landing	5, 7	
	Engine fire	Cruise and landing	5, 7	
	Engine failure (both engines)	Landing	8	
	Hydraulic system failure	Approach and landing	5, 7	

TABLE 35

Pilot Candidates for Instruments to be Eliminated by a Voice-Warning System

Vehicle	Pilots	Candidates for Elimination
UH-1	2	Secondary lights
	6	Engine air filter light
	3	Master caution
	10	Warning light (rpm)
	6	Fire detector switch
	8	Fire-warning indicator light
	1	Radio call designator
	3	Fuel gauge test switch
	1	Compass correction card
	3	Fuel pressure indicator
	2	Fuel quantity indicator
	3	Engine oil pressure indicator
	3	Engine oil temperature indicator
	2	Cargo caution decal
	2	Transmission oil pressure indicator
	3	Transmission oil temperature indicator
	1	Deleted
	2	Operating limits decal
	1	Engine caution decal
	2	Engine installation decal
	1	Compass slaving switch
	60	None
AH-1G	4	Master caution light
	7	Warning light (rpm)
	1	Omni indicator
	3	Fuel pressure indicator
	2	Transmission oil pressure indicator
	2	Engine oil pressure indicator
	1	Air vent
	2	Transmission oil temperature indicator
	2	Engine oil temperature indicator
	2	Fuel gauge test switch
	25	None
CH-47	1	Copilot's checklist
	1	Longitudinal cyclic trim indicator
	1	Pilot's checklist
	1	Cockpit air knobs
	17	None
CH-54	1	Master fire warning light
	1	IFF
	20	None

TABLE 35 (continued)

Vehicle	Pilots	Candidates for Elimination
OV-1	1	Wheel warning light
	1	Approach horizon indicator (ASN-33)
	1	Wheels and flaps indicator
	14	None

APPENDIX D

ANALYSIS OF CURRENT VISUAL DISPLAYS

TABLE 36

Analysis of UH-1 Visual Displays

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Engine air filter light	Indicates operation of engine air filter	Qualitative	Shows operation of engine air filter system	No		No
Master caution light	Alerts pilot to emergency	Qualitative	Alerts pilot to check caution and advisory panel	Yes	No, but provides visual backup of VWS	Yes
Warning light (rpm)	Shows low or high engine rpm or rotor rpm	Qualitative	Indication of abnormal engine or rotor rpm	Yes	No, but provides visual backup of VWS	Yes
Fire warning indicator light	Indicates engine fire	Qualitative	Alerts pilot to engine fire	Yes	No, but provides visual backup of VWS	Yes
Fuel gauge test switch	Tests operation of fuel gauge	Qualitative	Tests operation of fuel gauge	No		
Airspeed indicator	Primary flight					
Attitude indicator	Primary flight					
Altimeter indicator	Primary flight					
Fuel pressure indicator	Fuel pressure	Quantitative	Indication of operation of fuel pump and fuel distribution system	No		No
Fuel quantity indicator	Fuel remaining	Quantitative	Fuel management	Yes	Yes	No
Engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information about engine operation	Indirectly	Yes	No
Engine oil temperature indicator	Engine oil temperature	Quantitative	Diagnostic information about engine operation	Indirectly	Yes	No
Dual tachometer	Indicates rotor rpm and engine rpm	Quantitative	Provides indication of rotor and engine rpm	Yes	Yes	No
Radio compass indicator	Primary flight					
Vertical velocity indicator	Primary flight					
Transmission oil pressure indicator	Transmission oil pressure pressure	Quantitative	Diagnostic information about transmission operation	Yes	Yes	No
Transmission oil temperature indicator	Transmission oil temperature	Quantitative	Diagnostic information about transmission operation	Yes	Yes	No

TABLE 36 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Torquemeter indicator	Engine torque	Quantitative	Indicates amount of engine power being applied to transmission	No		No
Standby compass	Primary flight					
Main generator loadmeter	Electrical output and use	Quantitative	Shows electrical output for main generator	Yes	Yes	No
Voltmeter (d-c)	Electrical output (d-c) and use	Quantitative	Shows voltage output (d-c)	Yes	Yes	No
Gas producer tachometer indicator	Engine gas producer	Quantitative	Diagnostic information about engine operation	No		No
Marker beacon light	Precision approaches	Qualitative	Shows passage of outer, middle, and inner ILS markers	No		No
Standby generator loadmeter	Shows electrical output	Quantitative	Shows electrical output of backup generator	Yes	Yes	No
Voltmeter (a-c)	Shows voltage output (a-c)	Quantitative	Shows voltage available for use (a-c)	Yes	Yes	No
Exhaust gas temperature indicator	Engine EGT	Quantitative	Diagnostic information about engine operation	Yes	Yes	No
Turn and slip indicator	Primary flight					
Omni indicator	Primary flight					
Clock	Timing maneuvers and flight	Quantitative	Timing flight and flight maneuvers	No		No

TABLE 37

Analysis of AH-1G Visual Displays

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Master caution light	Fault warning	Qualitative	Alerts pilot to check caution and annunciator panel	Yes	No, but provides visual backup	Yes
Airspeed indicator	Primary flight					
Attitude indicator	Primary flight					
Altimeter indicator	Primary flight					
Warning light (rpm)	Indicates high or low rpm	Qualitative	Maintenance of desired rotor rpm	Yes	No, but provides visual backup	Yes
Dual tachometer indicator	Engine and rotor rpm	Quantitative	Shows engine performance	Yes	Yes	No
Turn and slip indicator	Primary flight					
Radio magnetic compass	Primary flight					
Rate of climb indicator	Primary flight					
Omni indicator	Primary flight					
Exhaust gas temperature (EGT)	EGT of engine	Quantitative	Diagnostic information for engine operation	Yes	Yes	No
Gas producer tachometer	Indication of fuel utilization	Quantitative	Diagnostic information for engine operation	No		No
Torquemeter	Engine power	Quantitative	Shows application of engine power to transmission	No		No
Clock	Timing flight and maneuvers	Quantitative	Timing flight	No		No
Volt-ammeter indicator	Shows electrical output	Quantitative	Voltage available	Yes	Yes	No
Fuel pressure indicator	Fuel pressure	Quantitative	Shows operation of fuel pump and fuel distribution system	Yes	Yes	No
Transmission oil pressure indicator	Transmission oil pressure	Quantitative	Main transmission oil pressure indicates operation of transmission	Yes	Yes	No
Engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information of engine operation	Indirectly		No

TABLE 37 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Fuel quantity indicator	Fuel remaining	Quantitative	Fuel management	Yes	Yes	No
Transmission oil temperature indicator	Transmission oil temperature	Quantitative	Indication of transmission operation	Yes	Yes	No
Engine oil temperature indicator	Engine oil temperature	Quantitative	Diagnostic information of engine operation	Indirectly	Yes	No
Fuel gauge test switch	Checks operation of fuel gauge	Qualitative	Tests operation of fuel gauge	No		No
Emergency collective hydraulic switch	Allows pilot to switch to emergency hydraulic system	Qualitative	Emergency use only	No		No
Caution and annunciator panel	Shows specific emergency conditions	Qualitative	Presents specific emergency conditions	Yes	Yes	No
Chip detector test switch (4 quadrant indicator) Gear box (42-degree) Transmission Gear box (90-degree) Engine	Tell which transmission has a chip. Pilot presses to test. Light will show which transmission has chip.	Qualitative	Chip detector	Yes	Yes	No

TABLE 38

Analysis of CH-47 Visual Displays

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Master caution light (pilot's)	Warning that emergency exists	Qualitative	Tells the pilot to look at the annunciator panel	Yes	No, but does provide visual backup to VWS	Yes
Torque meter (pilot's)	Engine torque	Qualitative/ quantitative	Pilot uses it to monitor engine power output	Yes	Yes. VWS only tells if difference in engine torques exists	No
Torque meter (copilot's)	Engine torque	Qualitative/ quantitative	Copilot uses it to monitor engine power output and to match engine torques	Yes	Yes. VWS only tells if difference exists in engine torques	No
Master caution light (copilot's)	Warning that emergency exists	Qualitative	Tells the pilot to look at the annunciator panel	Yes	No, but does provide visual backup to VWS	Yes
Airspeed indicator (pilot's)	Primary flight					No
Airspeed indicator (copilot's)	Primary flight					No
Attitude indicator (pilot's)	Primary flight					No
Attitude indicator (copilot's)	Primary flight					No
Altimeter (pilot's)	Primary flight					No
Altimeter (copilot's)	Primary flight					No
Rotary-wing tachometer (pilot's)	Primary flight/rotor rpm	Quantitative	Maintenance of rotor rpm	Yes	Yes, presents exact rotor rpm so that pilot can monitor desired rotor rpm	No
Rotary-wing tachometer (copilot's)	Primary flight/rotor rpm	Quantitative	Maintenance of rotor rpm	Yes	Yes, presents exact rotor rpm so that pilot can monitor desired rotor rpm	No
Radio magnetic indicator	Primary flight					No
Vertical velocity indicator (pilot's)	Primary flight					No
Vertical velocity indicator (copilot's)	Primary flight					No
Turn and slip indicator (pilot's)	Primary flight					No
Turn and slip indicator (copilot's)	Primary flight					No
Marker beacon light (pilot's)	Making precision approaches	Qualitative	Tells passage of outer, middle, and inner marker in ILS approach	No		No

TABLE 38 (continued)

Display	Use	Qualitative / Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Marker beacon light (copilot's)	Making precision approaches	Qualitative	Tells passage of outer, middle, and inner marker in ILS approach	No		No
Clock (pilot's)	Timing flight time and timing maneuvers	Quantitative	Timing flight and maneuvers	No		No
Clock (copilot's)	Timing flight time and timing maneuvers	Quantitative	Timing flight and maneuvers	No		No
Fire control handle No. 1 engine	Fire warning	Qualitative	Fire warning No. 1 engine	Yes	No, but provides visual backup	Yes
Fire control handle No. 2 engine	Fire warning	Qualitative	Fire warning No. 2 engine	Yes	No, but provides visual backup	Yes
No. 1 fire extinguisher agent switch	Extinguishing fire	Qualitative	Selects extinguisher to be used	No		No
No. 2 fire extinguisher agent switch	Extinguishing fire	Qualitative	Selects extinguisher to be used	No		No
Fire detector test switch	Test fire warning	Qualitative	Tests detection system	No		No
Loadmeter (a-c)	Shows voltage output for use	Quantitative	Voltage output and use (a-c)	Yes	Yes	No
Loadmeter (a-c)	Shows voltage output for use	Quantitative	Voltage output and use (a-c)	Yes	Yes	No
Loadmeter (d-c)	Shows voltage output for use	Quantitative	Voltage output and use (d-c)	Yes	Yes	No
Loadmeter (d-c)	Shows voltage output for use	Quantitative	Voltage output and use (d-c)	Yes	Yes	No
Longitudinal cyclic trim indicators (2)	Shows amount of cyclic trim being used	Quantitative	Used in triming vehicle during flight	No		No
Gas producer tachometers (2)	Indicates how efficiently fuel is being utilized	Quantitative	Good diagnostic indication of engine operation	No		No
Exhaust temperature indicators (2)	Shows most efficient engine operation and indicates possible presence of fire in engine	Quantitative	Good diagnostic indication of engine operation	Yes	Yes	No

TABLE 38 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Engine oil temperature indicators (2)	Shows amount of heat in engine oil	Quantitative	Good diagnostic indication of engine operation	No		No
Engine oil pressure indicators (2)	Used in conjunction with oil pressure, it is a good indication of oil quantity and engine operation	Quantitative	Good diagnostic indication of engine operation	Indirectly	Yes	No
Transmission oil pressure indicator	Transmission oil pressure	Quantitative	Indicates transmission oil pressure for any of five transmissions	Yes	Yes	No
Transmission oil temperature indicator	Transmission oil temperature	Quantitative	Indicates transmission oil temperature for any of five transmissions	Yes	Yes	No
Transmission oil pressure selector switch	Determines which of five transmission oil pressures will be displayed on indicator	Qualitative	Indicates which transmission oil pressure is being displayed	Yes	Yes	No
Transmission oil temperature selector switch	Determines which of five transmission oil temperatures will be displayed on indicator	Qualitative	Indicates which transmission oil temperature is being displayed	Yes	Yes	No
Fuel quantity indicator	Used to show remaining fuel quantity	Quantitative	Fuel management	Yes	Yes	No
No. 1 flight control hydraulic pressure indicator	Hydraulic pressure indication	Quantitative	Important for operation of flight control system	Yes	Yes	No
No. 2 flight control hydraulic pressure indicator	Hydraulic pressure indication	Quantitative	Important for operation of flight control system	Yes	Yes	No
Utility hydraulic pressure indicator	Utility hydraulic pressure indication	Quantitative	Important for operation of winch brakes, power steering, etc.	Yes	Yes	No
Fuel quantity selector switch	Selects fuel tank to be displayed	Qualitative	Selects fuel tank to be displayed	Yes	Yes	No
Radar altimeter (optional)	Primary flight					No
Gyrosyn compass indicator	Primary flight					No
Course indicator	Primary flight					No
Vne computer	Primary flight					
Caution and advisory panel	Presents specific faults to pilot or copilot	Qualitative			Yes	No

TABLE 39

Analysis of CH-54 Visual Displays

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Airspeed indicator (copilot's)	Primary flight					No
Torquemeter (copilot's)	Tells amount of engine load to transmission	Quantitative	Maintaining equal balance in engine torques	Yes	Yes	No
Triple tachometer (copilot's)	Tells rotor rpm, No. 1 engine rpm, and No. 2 engine rpm	Qualitative/ quantitative	Maintaining desired rotor rpm and engine operation	Yes	Yes	No
Master fire warning light (copilot's)	Primary source of engine fire warning	Qualitative	Engine fire warning	Yes	No, but provides visual backup	Yes
Attitude indicator (copilot's)	Primary flight					No
Radio magnetic indicator (copilot's)	Primary flight					No
Master caution light (copilot's)	Alerts copilot to look at annunciator panel for emergency	Qualitative	Alerts pilot to look at emergency annunciator panel	Yes	No, but provides visual backup	Yes
Altimeter (copilot's)	Primary flight					No
Rate of climb indicator (copilot's)	Primary flight					No
Turn and slip indicator (copilot's)	Primary flight					No
Clock (copilot's)	Used for timing flight time and maneuver time		Timing flight maneuvers	No		No
Caution and advisory panel	Indicates emergency conditions	Qualitative	Presents specific emergency conditions	Yes	Yes	No
Caution panel test switch	Turns on fault panel lights for test purposes	Qualitative	Tests fault panel operation	No		No
First stage hydraulic pressure indicator	Hydraulic pressure indicator	Quantitative	Indication of hydraulic pressure for operation of flight controls	Yes	Yes	No
Second stage hydraulic pressure indicator	Hydraulic pressure indicator	Quantitative	Indication of hydraulic pressure for operation of flight controls	Yes	Yes	No
Utility hydraulic pressure indicator	Brakes (AFCS)	Quantitative	Critical to operation of brakes	Yes	Yes	No

TABLE 39 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Fuel quantity indicator (forward)	Fuel remaining	Quantitative	Fuel management	Yes	Yes	No
Fuel quantity indicator (aft)	Fuel remaining	Quantitative	Fuel management	Yes	Yes	No
No. 1 engine gas generator tachometer	Indication of proper engine operation	Quantitative	Good diagnostic information for engine operation	No		No
No. 1 engine power turbine inlet temperature indicator	Indication of proper engine operation	Quantitative	Good diagnostic information for engine operation	No		No
No. 1 engine fuel flow indicator	Fuel management	Quantitative	Fuel management	No		No
No. 1 engine pressure ratio indicator	Engine operation and efficiency	Quantitative	Good diagnostic information for engine operation	No		No
No. 1 engine oil temperature indicator	Engine oil temperature	Quantitative	Good diagnostic information for engine operation	Indirectly	Yes	No
No. 1 engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information for engine operation	Indirectly	Yes	No
No. 2 engine gas generator tachometer	Indication of engine operation	Quantitative	Diagnostic information for engine operation	No		No
No. 2 engine power turbine inlet temperature indicator	Indication of engine operation	Quantitative	Diagnostic information for engine operation	No		No
No. 2 engine fuel flow indicator	Fuel management	Quantitative	Fuel management	No		No
No. 2 engine pressure ratio indicator	Engine operation and efficiency	Quantitative	Diagnostic information for engine operation	No		No
No. 2 engine oil temperature indicator	Engine oil temperature	Quantitative	Diagnostic information for engine operation	Indirectly	Yes	No
No. 2 engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information for engine operation	Indirectly	Yes	No
Hoist cable length indicator	Amount of cable remaining and used	Quantitative	Amount of cable remaining	No		No

TABLE 39 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Hover indicator (flight director)	Primary flight					No
Cable tension indicator	Indicates the amount of force on the hoist cable	Quantitative	Indicates amount of force or weight on cable	No		No
Transmission oil temperature indicator	Transmission oil temperature, main transmission	Quantitative	Transmission operation	Yes	Yes	No
Transmission oil pressure indicator	Transmission oil pressure, main transmission	Quantitative	Transmission operation	Yes	Yes	No
Performance indicator (flight director)	Primary flight					No
VOR course indicator	Primary flight					
Winch hydraulic temperature indicator	Indication of winch operation	Quantitative	Operation of winch depends upon hydraulic	No		No
Clock (pilot's)	Timing flight and timing maneuvers	Quantitative	Timing maneuvers	No		No
Airspeed indicator (pilot's)	Primary flight					No
Torquemeter (pilot's)	Indicates application of engine power to transmission	Quantitative	Maintaining torque balance between engines	Yes	Yes	No
Triple tachometer (pilot's)	Indicates rotor :pm, No. 1 engine rpm, and No. 2 engine rpm	Qualitative/ Quantitative				
Master fire warning light (pilot's)	Warning of engine fire	Qualitative	Fire warning	Yes	No, but provides visual backup of VWS	Yes
Master caution warning light	Tells pilot to monitor annunciator panel for emergency	Qualitative	Alerts pilot of emergency condition	Yes	No, but provides visual backup of VWS	Yes
Attitude indicator (pilot's)	Primary flight					
Radio magnetic indicator (pilot's)	Primary flight					
Rate of climb indicator (pilot's)	Primary flight					
Turn and slip indicator (pilot's)	Primary flight					

TABLE 40

Analysis of OV-1 Visual Displays

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Airspeed indicator	Primary flight					No
Master caution light	Alerts pilot to look at annunciator panel	Qualitative	Master warning light	Yes	No	Yes
Caution and advisory panel	Presents specific faults	Qualitative	Presents specific emergencies	Yes	Yes	No
Wheels warning light	Indicated failure to lower landing gear	Qualitative	Alerts pilot of failure to lower landing gear	Yes	No, but due to heavy voice messages from air traffic control the voice warning could be missed. Suggest leaving light warning	No
Approach horizon indicator	Primary flight					
Auto feather armed light	Indicates that the auto feather system will take over feathering of an engine if failure occurs	Qualitative	Auto feather is armed	No		No
Altimeter indicator	Primary flight					No
Veloci / and steering indicator (VSI)	Primary flight					No
Accelerometer	Primary flight					No
Vertical gyro indicator (VGI)	Primary flight					No
Rate of climb indicator	Primary flight					No
Radar altimeter	Primary flight					No
Clock	Timing maneuvers and flight	Quantitative	Timing maneuvers	No		No
Gyrocompass control panel	Primary flight					No
Course indicator	Primary flight					No
Wheels and flaps indicator	Indicates the extension of gear or flaps	Qualitative/ quantitative	Visual indication of wheel and flap extension	No	Yes	No
Turn and slip indicator	Primary flight					
MD-2 oxygen regulator	Presents oxygen flow and quantity	Qualitative/ quantitative	Shows oxygen quantitative and qualitative use rate	No		No
Ratio magnetic compass indicator	Primary flight					No
Camera pulse light	Indicates operation of camera	Qualitative	Shows camera operation	No		No
VOR-ADF selector panel	Primary flight					No

TABLE 40 (continued)

Display	Use	Qualitative/ Quantitative	Importance	Overlaps With VWS	Displays Useful Information Other Than That Presented by VWS	Possible Elimination
Marker beacon glide slope control panel	Primary flight					No
No. 1 engine torquemeter indicator	Shows engine power applied to propeller	Quantitative	Maintenance of engine torque	No		No
No. 2 engine torquemeter indicator	Shows engine power applied to propeller	Quantitative	Maintenance of engine torque	No		No
No. 1 engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information for engine operation	Yes	Yes	No
No. 2 engine oil pressure indicator	Engine oil pressure	Quantitative	Diagnostic information for engine operation	Yes	Yes	No
Fuel flow rate indicator	Rate of fuel usage	Quantitative	Fuel management	No		No
Fuel quantity indicator	Fuel remaining	Quantitative	Fuel management	Yes	Yes	No
Volt-ammeters (2)	Shows output of generators and indirectly the usage	Quantitative	Shows generator output	Yes	Yes	No
Hydraulic pressure indicator	Hydraulic pressure	Quantitative	Hydraulic pressure required for lowering gear and flaps	Yes	Yes	No
No. 1 engine exhaust gas temperature indicator	EGT for No. 1 engine	Quantitative	Diagnostic information for engine operation	Yes	Yes	No
No. 2 engine exhaust gas temperature indicator	EGT for No. 2 engine	Quantitative	Diagnostic information for engine operation	Yes	Yes	No
No. 1 engine tachometer	Indicates engine rpm	Quantitative	Maintenance of engine power	Yes	Yes	No
No. 2 engine tachometer	Indicates engine rpm	Quantitative	Maintenance of engine power	Yes	Yes	No
No. 1 engine propeller tachometer	Indicates propeller rpm	Quantitative	Maintenance of desired propeller rpm	No		No
No. 2 engine propeller tachometer	Indicates propeller rpm	Quantitative	Maintenance of desired propeller rpm	No		No
No. 1 engine fire emergency control handle	Indicates fire in No. 1 engine	Qualitative	Fire warning and control	Yes	No, but provides visual backup to VWS	Yes
No. 2 engine fire emergency control handle	Indicates fire in No. 2 engine	Qualitative	Fire warning and control	Yes	No, but provides visual backup to VWS	Yes

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13. ABSTRACT

This report describes an analytical study that was intended to serve as a basis for the application of voice-warning systems (VWS) for the UH-1B and UH-1D (Huey), AH-1G (Cobra), CH-47 (Chinook), CH-54 (Skycrane), and OV-1 (Mohawk). The following problems of installing a VWS in these Army aircraft were studied: (1) the identification and selection of messages for maximum effectiveness; (2) the determination of priority sequences; and (3) the integration of the VWS into existing cockpits. The study involved the collection of basic data and the conduct and validation of mission analyses, operational sequence diagrams, task analyses, aircraft configuration analyses, pilot opinion surveys, and Army aircraft accident analyses. In this report, priority sequences are derived for all major emergencies for the six vehicles; further analytical effort is described which reduced the list to 20 messages for inclusion in the VWS. For each aircraft, 2 lists of 20 messages are proposed; one list assumes additional sensors, while the second assumes the current sensor system. Recommendations are made for message structure and content, priority sequences, integration of the VWS with the current visual-warning system, general sensor requirements, interlocking between VWS messages, and other related considerations.

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Warning devices						
Auditory warnings						
Displays						
Aircraft displays						
Voice warning						
Army aircraft						
Mission analysis						
Task analysis						
Display development						
Systems integration						
UH-1						
AH-1G						
CH-47						
CH-54						
OV-1						

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